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# TRANSACTIONS

OF THE

# AMERICAN SOCIETY

OF

# CIVIL ENGINEERS

(INSTITUTED 1852)

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# CONTENTS

## PAPERS


| No. | | PAGE |
|---|---|---|
| 1143 | **NOTES ON THE REPLACING OF THE SUPERSTRUCTURE OF THE HARLEM RIVER SHIP CANAL BRIDGE.** | |
| | By **Horace J. Howe** | 1 |
| | Discussion: | |
| | By Lincoln Bush | 23 |
| | Martin Gay | 24 |
| | St. John Clarke | 26 |
| | Theodore Belzner | 27 |
| | Frank W. Skinner | 28 |
| | Horace J. Howe | 30 |
| 1144 | **PRECARIOUS EXPEDIENTS IN ENGINEERING PRACTICE.** | |
| | By **John Hawkesworth** | 32 |
| | Discussion: | |
| | By Eugene W. Stern | 46 |
| | W. W. Crosby | 48 |
| | J. S. Branne | 50 |
| | Andrews Allen | 52 |
| | Guy B. Waite | 55 |
| | J. H. Gandolfo | 57 |
| | John Hawkesworth | 59 |
| 1145 | **WATER SUPPLY FOR THE LOCK CANAL AT PANAMA.** | |
| | By **Julio F. Sorzano** | 61 |
| | Discussion: | |
| | By C. E. Grunsky | 91 |
| | H. F. Hodges | 96 |
| | Theodore Paschke | 106 |
| | Allen Hazen | 108 |
| | C. M. Saville | 112 |
| | Julio F. Sorzano | 133 |
| 1146 | **THE IMPROVED WATER AND SEWAGE WORKS OF COLUMBUS, OHIO.** | |
| | By **John H. Gregory** | 206 |
| | Discussion: | |
| | By Joseph W. Ellms | 324 |
| | Julian Griggs | 325 |
| | C-E. A. Winslow | 328 |
| | R. D. Scott and R. F. McDowell | 330 |
| | Samuel Tobias Wagner | 334 |
| | J. Corbett | 335 |
| | W. R. Copeland | 337 |
| | W. A. Sperry | 342 |
| | J. W. Sale | 345 |
| | C. P. Hoover | 354 |
| | C. B. Hoover | 359 |
| | A. Elliott Kimberly | 379 |

| No. | | PAGE |
|---|---|---|
| 1146 | Discussion *(Continued)*: | |
| | SAMUEL RIDEAL | 388 |
| | ALEXANDER POTTER | 390 |
| | GILBERT FOWLER | 394 |
| | WILLIAM GAVIN TAYLOR | 397 |
| | ALLEN HAZEN | 399 |
| | WILLIAM B. FULLER | 400 |
| | EMIL KUICHLING | 402 |
| | LANGDON PEARSE | 406 |
| | RUDOLPH HERING | 407 |
| | GEORGE A. JOHNSON | 415 |
| | GEORGE W. FULLER | 419 |
| | JOHN H. GREGORY | 426 |
| 1147 | **AGREEMENTS FOR BUILDING CONTRACTS.** | |
| | By **William B. Bamford** | 438 |
| | Discussion: | |
| | By NORMAN R. MCLURE | 478 |
| | WILLIAM V. POLLEYS | 479 |
| | CHARLES H. HIGGINS | 481 |
| | W. G. WILKINS | 483 |
| | WILLIAM A. BORING | 486 |
| | J. C. WAIT | 488 |
| | W. L. BOWMAN | 491 |
| | CHARLES A. RUGGLES | 493 |
| | OSCAR LOWINSON | 496 |
| | E. T. THURSTON, JR. | 497 |
| | JOHN MASON BROWN | 502 |
| | J. A. L. WADDELL | 510 |
| | DEWITT V. MOORE | 515 |
| | LESLIE H. ALLEN | 520 |
| | WILLIAM B. BAMFORD | 525 |
| 1148 | **UNDERPINNING THE CAMBRIDGE BUILDING, NEW YORK CITY.** | |
| | By **T. Kennard Thomson** | 553 |
| | Discussion: | |
| | By HENRY GORTON OPDYCKE | 565 |
| | E. A. YATES | 566 |
| | OGDEN MERRILL | 567 |
| | OSCAR LOWINSON | 568 |
| | J. C. MEEM | 569 |
| | T. KENNARD THOMSON | 570 |
| 1149 | **THE EFFECT OF ALKALI ON CONCRETE.** | |
| | By **George Gray Anderson** | 572 |
| | Discussion: | |
| | By R. A. HART | 587 |
| | RUDOLPH HERING | 592 |
| | RICHARD L. HUMPHREY | 598 |
| | GEORGE F. MORSE | 601 |
| | RICHARD H. GAINES | 602 |
| | THOMAS H. MEANS | 606 |
| | F. E. ROBERTSON | 608 |
| | PHILO H. BATES | 608 |
| | E. P. GOODRICH | 611 |
| | W. E. BELKNAP | 612 |
| | GEORGE GRAY ANDERSON | 617 |

# MEMOIRS OF DECEASED MEMBERS


| | PAGE |
|---|---|
| HENRY FURLONG BALDWIN, M. AM. SOC. C. E. | 621 |
| CLIFFORD BUXTON, M. AM. SOC. C. E. | 623 |
| WILSON CROSBY, M. AM. SOC. C. E. | 625 |
| JOHN HALL EMIGH, M. AM. SOC. C. E. | 628 |
| HENRY CYPRIAN HUMPHREY, M. AM. SOC. C. E. | 630 |
| HENRY MAYNADIER STEELE, M. AM. SOC. C. E. | 631 |
| JOHN JOSEPH HORAN, ASSOC. M. AM. SOC. C. E. | 634 |


# PLATES


| PLATE | | PAPER | PAGE |
|---|---|---|---|
| I. | South Span, Harlem Ship Canal Bridge, Being Made Ready for Final Move, and North Span at Beginning of Erection | 1143 | 5 |
| II. | Old Draw-Span Ready for Final Move, and Old and New Draw-Spans | 1143 | 9 |
| III. | New Draw-Span in Readiness to Move, and Present Harlem Ship Canal Bridge | 1143 | 11 |
| IV. | Coteau Bridge, and Brunot Island Bridge on Falsework Floating on Barges | 1143 | 29 |
| V. | Topographical Map, Showing Ridge at Escoval, Canal Zone | 1145 | 129 |
| VI. | Map of Part of Lake Gatun, Canal Zone | 1145 | 165 |
| VII. | Views of Dam, and of Scioto River Pumping Station and Water Purification Works, Columbus, Ohio | 1146 | 213 |
| VIII | Scioto River Pumping Station and Water Purification Works: Plans Showing Location of Structures | 1146 | 221 |
| IX. | Scioto River Pumping Station and Water Purification Works: General Plan, Showing Arrangement of Structures and Piping | 1146 | 227 |
| X. | Plan of Scioto River Pumping Station | 1146 | 229 |
| XI. | Scioto River Pumping Station: Section Through Engine-Room, Looking East | 1146 | 231 |
| XII. | Water Purification Works: Floor Plans of Main Building | 1146 | 233 |
| XIII. | Water Purification Works: Substructure of Head-House | 1146 | 235 |
| XIV. | Interior Views of Filters and Filtered-Water Reservoir, Showing Construction, and Scioto River Pumping Station | 1146 | 239 |
| XV. | Plan and Sections of Lime Saturators | 1146 | 241 |
| XVI. | Plan and Sections of Mixing Tanks | 1146 | 243 |
| XVII. | Plans and Sections of Gate-House and Main Dividing Wall of Settling Basins | 1146 | 245 |
| XVIII. | Details of Filter Gallery | 1146 | 247 |
| XIX. | Details of Filters | 1146 | 249 |
| XX. | Details of South Filtered-Water Reservoir | 1146 | 251 |
| XXI. | Interior Views of Filter Gallery, Chemical Mixing Room, Lime Saturator House, and View of Settling Basins | 1146 | 253 |
| XXII. | East Side Sewage Pumping Station: Plan and Section Showing Machinery | 1146 | 281 |
| XXIII. | General Plan of Sewage Purification Works | 1146 | 285 |
| XXIV. | Sewage Purification Works: Location of Structures and Plan of Pipes and Conduits | 1146 | 289 |
| XXV. | Plans and Sections of Septic Tanks | 1146 | 291 |
| XXVI. | Views of Primary and Secondary Septic Tanks | 1146 | 293 |
| XXVII. | Sections of Gate-House | 1146 | 295 |

| PLATE | | PAPER | PAGE |
|---|---|---|---|
| XXVIII. | Plan of Sprinkling Filter No. 3. | 1146 | 297 |
| XXIX. | Details of Sprinkling Filters | 1146 | 299 |
| XXX. | Views of Sprinkling Filters, During Construction | 1146 | 301 |
| XXXI. | Plan and Sections of Settling Basins | 1146 | 303 |
| XXXII. | Views of Sprinkling Filters Nos. 1 and 2, and of Septic Tanks | 1146 | 305 |
| XXXIII. | Details of Pump-House | 1146 | 307 |
| XXXIV. | Views Showing Settlement of Street, Etc., in Thirty-third Street, in Front of Cambridge Building | 1148 | 555 |
| XXXV. | Views Showing Cracks in Wall and Ceiling of Main Floor, and Settlement in Area, Cambridge Building | 1148 | 557 |

AMERICAN SOCIETY OF CIVIL ENGINEERS
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# TRANSACTIONS

Paper No. 1143

## NOTES ON THE REPLACING OF THE SUPERSTRUCTURE OF THE HARLEM SHIP CANAL BRIDGE.*

By Horace J. Howe, M. Am. Soc. C. E.

With Discussion by Messrs. Lincoln Bush, Martin Gay, St. John Clarke, Theodore Belzner, Frank W. Skinner, and Horace J. Howe.

The highway in upper Manhattan which was known as King's Bridge Road in Washington's time was the only connection by land from New York City to Albany and Boston. Going north from Fort Washington, its location is easily surmised to-day, winding along the base of the foot-hills to the present Ship Canal, thence branching to the right, over Farmer's Bridge (built in 1759), and then to the left and over King's Bridge (built in 1693), to Westchester County, crossing the tidal stream early named Spuyten Duyvil Creek.

In the celebrated retreat to White Plains (1776), a dozen miles to the northeast, these bridges were useful; and the British likewise found them so, on their return from that battle ground, in their rapid march to capture Fort Washington. These operations were in a way typical of the border warfare in this vicinity during the ensuing seven years, or until the evacuation of the city (1783), and no doubt tested the bridges severely as to their loading and as arteries of traffic. King's Bridge was 24 ft. wide and Farmer's Bridge 18 ft. wide.

Happily, such conditions did not recur, and it was not until 1900 that a third bridge over the creek at Broadway came to their assistance.

* Presented at the meeting of January 5th, 1910.

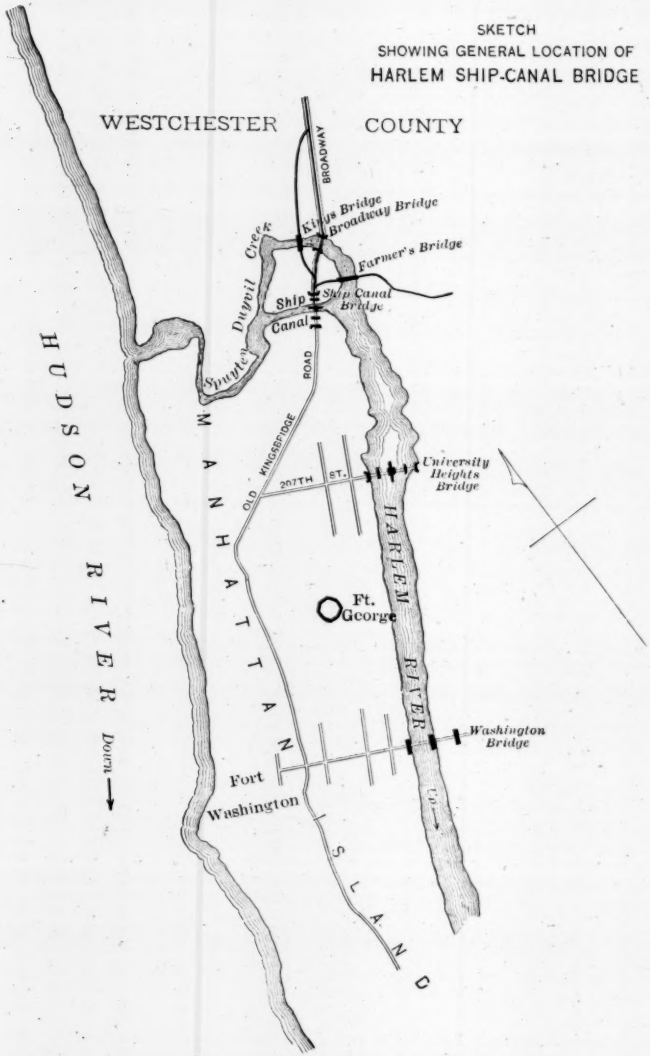
SKETCH
SHOWING GENERAL LOCATION OF
HARLEM SHIP-CANAL BRIDGE
WESTCHESTER COUNTY
BROADWAY
Kings Bridge
Broadway Bridge
Farmer's Bridge
Dyckman Creek
Ship Canal
Ship Canal Bridge
Spuyten Duyvil
HUDSON RIVER
Down
MANHATTAN
OLD KINGSBRIDGE ROAD
207TH ST.
University Heights Bridge
HARLEM RIVER
Ft. George
Washington Bridge
Fort Washington
Up
ISLAND

FIG. 1.

Owing to the march of progress, all three will be taken down in the near future, and the former stream will be filled in completely.

This is due primarily to the excavation by the United States Government of what is known as the Ship Canal (1894), a waterway which connects the Harlem and the Hudson, saves distance to points on the Harlem, and enables 1 000-ton barges to cut across to the East River and avoid the dangers of the trip around the Battery. It required a swing bridge with equal waterways of 100 ft. in the clear, and at each end an approach span 100 ft. long at King's Bridge Road, or Broadway, as it is now called.

The moving of this recently built bridge and the substitution of the present one is the subject of this paper.

The change was agreed to by four interested parties, and resulted, in short, in a bridge with: Three elevated tracks for the Interborough Rapid Transit Company; two surface tracks for the Metropolitan Street Railway Company; an additional track underneath (four in all) for the New York Central and Hudson River Railroad; and a roadway increased to 35 ft. in width, and sidewalks increased to 7 ft. in width.

The City of New York, furthermore, took over the old superstructure for use at University Heights, a mile up the river.

The work was done by John B. McDonald (Contract No. 1 of February 21st, 1900), under the direction of the Board of Rapid Transit Commissioners.

Permission from the War Department was duly obtained, subject to the condition of maintaining for the new spans at all times a clear waterway, 250 ft. wide and 15 ft. deep, and a minimum clearance of 24 ft. above high water of spring tides.

Permission was obtained also from the Bridge Department of the City of New York, which considered the neighborhood carefully, and issued a permit allowing a "closing of the said Ship Canal Bridge to street travel for a total time of five days of which not more than three days shall be consecutive."

Thus the preliminaries were arranged, but direct contract work was delayed until 1905, which permitted a study of the situation in detail.

The Harlem River is an inland stream, about 6 miles long, subject to tidal influences from both ends—at the west *via* the Narrows and the Hudson River, and at the east *via* Long Island Sound and Hell

Gate. The mean rise near the bridge is 4.1 ft., and the extreme range is perhaps 10 ft. The velocity of the current at mid-tide is somewhat more than 2 miles an hour; but the tide and velocities are very variable and not to be anticipated. There is considerable summer traffic on the river.

Soundings were taken at various points, and Messrs. Terry and Tench, the sub-contractors, decided to construct falsework for the new draw-bridge off shore at 216th Street (Manhattan), ½ mile above the site, 221st Street, and to construct the approach spans on shore near Broadway. It was thought that dredging would not be necessary.

Pile-driving began at 216th Street, in May, 1905. There were 15 bents of 10 piles each, and 3 bents of 15 each at the center, all being spaced carefully with relation to the floor-beams and the pivot. Besides, two clusters were driven, one at each outside end, for protection against river craft, and some others to connect with the bank. The piles were of good size, as long as 55 ft. on the deeper side, and were driven practically to refusal, penetrating from 10 to 20 ft. into the river bed, but not to bed-rock. The capping and bracing were finished in September.

*South Approach Span.*—Meanwhile, the framing, bracing, and decking of the bents for the south approach span was completed by August 1st, and erection begun.

The total force at this time was 50 men, using two scows (100 by 30 ft.), and a well-equipped steam lighter with a steel derrick. The riveting was completed by October 1st, and the special work for the surface tracks by October 14th. There were 14 000 field rivets.

The general scheme was to move the old span out and the new one in, simultaneously, by land and water.

The span, having been built with a panel projecting over the bulkhead, was at this time resting at that end on the cribbing of the scow, and at the other end on two sets of cribs on railroad trucks and tracks. All masonry parapets interfering with the sliding of the new span eastward to place were removed, anchor-bolts were cut, and steel wedges inserted, and a double track was lined and surfaced parallel to the bulkhead, and at its level.

On October 17th, the new span, weighing 330 tons, was moved diagonally northwest about 50 ft. to a point 115 ft. west of its final position, thereby providing room for the two scows to act in tandem. (Fig. 1, Plate I.) All end posts were then freed, and the span was sup-

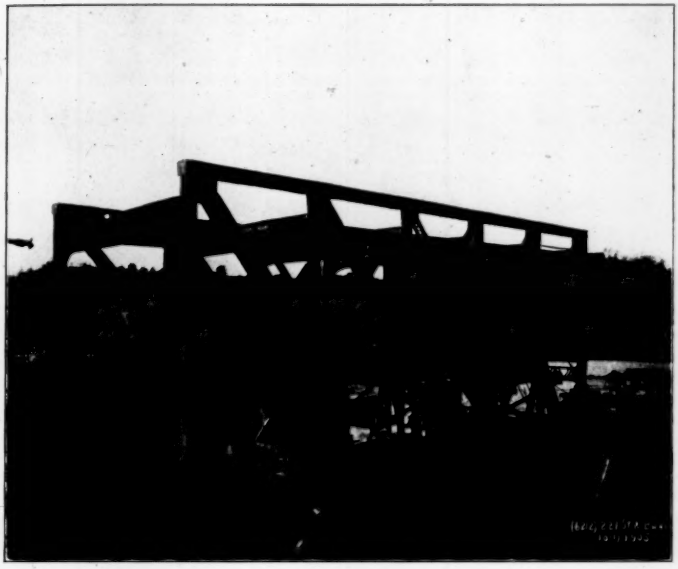

FIG. 1.—SOUTH SPAN, HARLEM SHIP CANAL BRIDGE, BEING MADE READY FOR FINAL MOVE.

FIG. 2.—NORTH SPAN, HARLEM SHIP CANAL BRIDGE, AT BEGINNING OF ERECTION.

ported at intermediate panel points by a scow at the north end and the two sets of trucks at the south end.

On October 19th, at low water (5 A. M.), the old approach span, weighing 240 tons, having been cribbed up on trucks at one end, was wedged up on the scow at the other end. At 8 A. M., the north end rose clear of the pier. Some delay ensued, and it was not until 10.45 A. M. that the strain was put on the wire ropes from the drums of the stationary engine. Two pulley blocks were used in connecting with the trucks of the old span, and one three-sheave block with the new. Both were adequate, and the entire mass was moved out easily, until the old span was entirely clear of the masonry. Owing to the settlement of the tracks by this move, and to the fact that the tide had risen, the 4-in. clearance of grillage beams and abutment was reduced to scraping distance, and for a few minutes the success of the last half of the moving was a matter of conjecture. However, the span was moved in 14 min.

A temporary plank roadway was begun at once, and the first vehicle passed over the bridge at 5.45 P. M. At noon the Barber Asphalt Company began concreting the buckle-plate floor, and completed the east roadway on October 25th.

*North Approach Span.*—The erection of separate cribs for the new 112-ft. span was begun on September 5th, 1905, about 300 ft. east of Broadway. (Fig. 2, Plate I.) The trusses were at 39-ft. centers, and there were five panels, the same as in the south span; the total weight was 380 tons. Cribs were erected under alternate floor-beams, leaving one panel overhanging the bulkhead. The foundation course was composed of twelve 16 by 16-in. pieces laid side by side; the second course was four 16 by 16-in. pieces, square with the first, and the top half of each crib was made up of three 12 by 12-in. pieces of diminishing lengths. The level of the top was made 10 in. higher than the ultimate position of the bottom of the floor-beams.

Erection was begun on September 12th, and took two weeks. Then riveting began, and was finished on October 28th. There were 16 000 field rivets, practically all driven by power. Meanwhile, the New York Central and Hudson River Railroad Company completed the new north abutment.

During this time, much care was taken in lining, squaring, and leveling the trusses and floor-beams. Owing to the direction of the

shore line, it was impossible to erect the span exactly square with its final position at Broadway, and it was necessary to roll it and float it 20 ft. to the south. To do this, four tracks were laid, a pair of trucks was placed under each north post, and the weight was deposited on them. A scow, as before, took the other end, and, by the aid of a stationary engine with its lines, the move was easily made, and the two south panels extended over the water. There was not room enough for another scow, and so the weight was again dropped on the original cribs and the scow floated off. This left the span exposed to river craft.

At the next ebb tide, the second panel point was supported by a scow. Likewise, the weight at the north end was transferred at its second panel point, and all was made ready for a run westward. There were two tracks on the shore end. On November 2d the span was moved westward to near Broadway by using a stationary engine and deadman.

The next step—the track extension westward—was a puzzling problem, for the channel was only 40 ft. wide between pier and bulkhead, and the latter curved sharply to the south, west of Broadway, and it was important to insure the different clearances of the scows. Finally, a track of 200 ft. radius was laid out, carefully eased off at the approach, super-elevated and braced against the neighboring bank.

It was foreseen that the cribs would have to turn on the trucks, in a manner similar to that of a car body, and, to provide for this, two iron bearing plates, well greased, were set in place, but not fastened. The north end of the old span required three trucks, one under each chord, and the new span required two double trucks, a pair under each point of support. All walls, anchor-bolts, steel wedges, etc., were regulated as before.

On November 6th at low water (10.30 A. M.), a scow was floated under the south end of the old span, and 3 ft. west of the other scow. The clearance of the northwest corner of the pier was 8 in., and of the northeast corner 18 in.

A stationary engine had been placed 200 ft. west, and lines had been passed to the trucks of both spans and attached. The derrick-lighter was placed east of both spans and connected with a deadman west of the bridge. It was calculated that the lighter would counteract the action of the tide against the scows, and in general would preserve proper relations with the trucks.

The combined effect of the pumps and the tide caused the old span to rise clear of the pier at 2.00 P. M. An hour or so later, levels showed the new span to be an average of 10 in. above the bridge seat.

At 3.25 P. M., the signal was given to move, and in 2 min. the combined mass had moved 70 ft., and the westerly truck was at the west end of the curve. An examination of the bearing plates at the west trucks of the old span showed that the upper plates had slid along the lower ones and were nearly off; also, that the axles of the east trucks under the old span, and of all the trucks of the new span, were bending or bowing up in the middle, under the excessive strain.

This condition was partly caused by the undue pushing of the lighter. A halt was called, the cribs were jacked up, and the old span was moved separately to a clearance point, shortly after 5.00 P. M.

At 5.45 P. M. the new span was moved to place, the lines were cast off, and pumps set to work. By 7.00 P. M. the south end was at rest.

The north end was landed by using 60-ton jacks, after a hard struggle lasting until midnight. The liquid seemed to have affected the packing and caused leaks, while the tide caused much variation in the cribbing from time to time.

The bridge had been closed to vehicles from 1.30 to 10.15 P. M., and to foot passengers from 3.00 to 5.00 P. M. Planking had been laid previous to moving.

A week later, the old north approach span was loaded on two scows, and, with the help of two tugs, was floated to the south shore, west of the bridge, rolled on tracks far enough to clear the canal, and then cribbed up until required, a year later.

The asphalt roadway was completed on November 17th, 1905.

*The New Draw-Span.*—The erection of the new draw-span began early in December, and continued until the strike of January 1st, 1906. Union labor had been getting $4.50 for 8 hours' work and wanted $5.00. The strike lasted until February 12th, when a compromise was effected. Little of importance occurred meantime. The weather was particularly fine, but later became an element of expense. Some temporary wood bracing was put into the old approach spans for protection, and odd jobs were attended to. Also, the New York Central and Hudson River Railroad began running trains under the north span.

On February 14th, power-riveting began on the roadway stringers and floor-plates of the motor platforms. The force was soon increased

to 45 men. All cross-girders had been lined and leveled some weeks before, but required constant examination. The concentration of loading had been near the middle bents, but, of course, decreased as the top work advanced. Two derrick-lighters were moved about the structure on both sides, and bumped the piles more or less; and the stationary engine and riveting guns added somewhat to the vibrations.

On February 24th, the new south span was connected with the viaduct south of it. The temporary terminal station at 221st Street was opened a month later.

Cracks having been discovered in the 27 by $\frac{7}{8}$-in. connecting angle plates of the pivot and loading girders, new ones were ordered, and arrived early in March. After much cutting out of all rivets affected, the girders were riveted up with 1-in. rivets as before. It was decided that the material was good, but having been shipped in an exposed manner, attached to the girder, the damage had occurred in transit.

The maximum force was 70 men, including 8 riveting gangs of 4 men each. In this span 122 000 field rivets and 7 000 bolts were used. By the end of March the main trusses, with sway and lateral bracing, were erected. The eye-bars had been easily connected, as the ends of the trusses had been raised $1\frac{1}{2}$ in.; but the cross-strut at the king-posts was a tighter fit.

The adjustment of the machinery in connection with the electric motors proceeded until the last of April, and from this time until the middle of June, the draw-span remained on the falsework.

*Moving the Old South Approach Span.*—On May 1st, 1906, the old south approach span, weighing 240 tons, was floated to University Heights on two scows, after having been run off the bulkhead on three tracks. There was some delay at one corner in detaching it from the shore crib. The contractors ordered fresh jacks, and the crib timbers were cut and slashed in order to drop that end clear of its support. This was a typical operation.

It was high tide when the destination was reached, and the scows were straddling the end draw-pier. Rollers were ready on the pier, and there was no delay in working the span westward to the temporary cribbing on the bulkhead; whence, a few days later, it was rolled still farther west to the final position on three well-braced columns.

*Work at the Old Draw-Span.*—The first thing done in the work at the old draw-span was the chocking of the eye-bars of the top chord

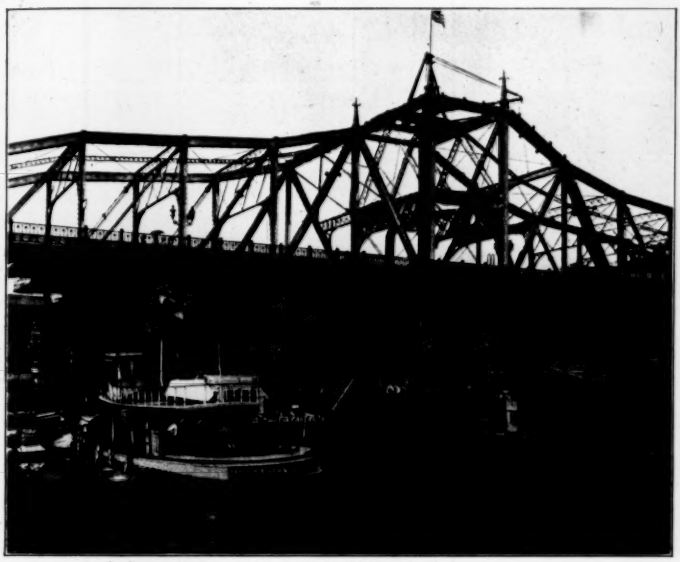

FIG. 1.—OLD DRAW-SPAN READY FOR FINAL MOVE TO UNIVERSITY HEIGHTS.

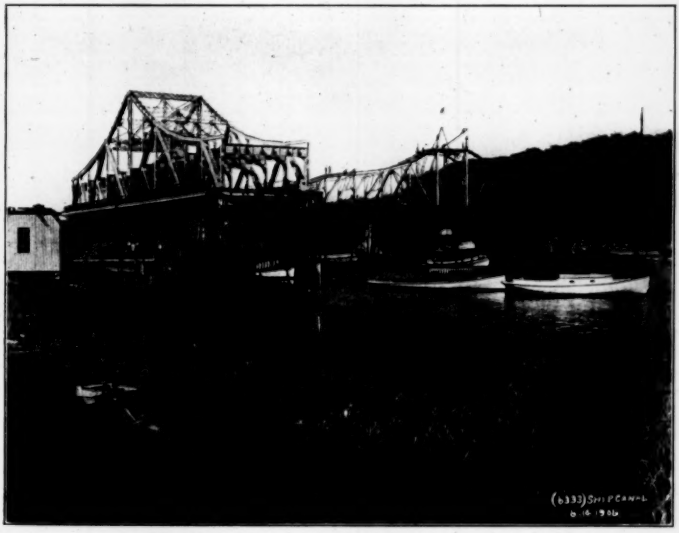


FIG. 2.—OLD DRAW-SPAN FLOATING BY NEW SPAN, EN ROUTE TO UNIVERSITY HEIGHTS.

in order to provide for compressive strains while in transit to University Heights. This was early in May, 1906. As the new draw was to rest on a center pivot, and was to have only a few balance wheels or "tippers" on the outside rim, it was necessary to dress the masonry down, and furnish filler plates to take the new casting (8 ft. 6 in. in diameter), and transfer the weight to the pier; but, as the old rack was to gear with two pinions with vertical shafts, as before, it was important that the center of the rack and the center of the pivot should correspond.

Precise measurements were accordingly taken inside the old drum and resulted in finding and referencing the true point. This was then transferred by transit sidewise, up over the drum and thence to the roadway, where it became the governing point in lining up the spans.

Late in May, the old anchor-bolts were cut, and the center-pin and casting were suspended, together with the radiating rods and struts. The old rack was left in place, and a new one was put in at University Heights. One pinion was disconnected.

The old wooden trestle, used as an oiling platform, was torn down, as it was designed to oil the new shafting while the draw was closed.

Four submarine armored cables were laid across the channels in a trench, up the center pier, and through drilled holes in the coping. Meantime, electric motors had been installed at the 216th Street site, with a view to the immediate operation of the bridge on its arrival at Broadway. All riveting had been completed, and the compressors had been removed.

As it was necessary to use four scows to carry the draw, some of the piles of the platform had to be removed. This left two bents at each end and five bents under the center, supporting the entire weight of the draw and the platform. The removal of the piles was completed on May 22d. Levels, taken two days later, showed that there had been no settlement. The total settlement for the year, however, had been 3 in.

On the new draw as well as the old, the true center of the pivot was carried up precisely, and located on the roadway. Measurement to the curved end faces showed a discrepancy of $\frac{1}{4}$ in., an error not at all serious in its relation to the clearances of the approach spans.

Temporary plank sidewalks and half of the roadway were laid.

In the early part of June, as the days went by and the impending move was not made, it was reported that the draw was creeping south-

ward on its falsework, now much reduced, as stated. Observation showed that some of the piles were out of plumb, and that the caps were sagging on the center bents. Fixed lines by instrument were established on shore, and sights were taken at regular intervals for the next week or more; but only temperature variations were to be seen. The average load on each pile was 12 tons.

There was no disposition to delay the work, it may be imagined, particularly as the center pier at University Heights was completed; and operations were prosecuted with great energy by Superintendent J. F. Sullivan and his force of 50 men, up to June 14th, when the old draw was moved up the river to its present location. On that day at low water (10.15 A. M.) it was swung for the last time at Broadway through an angle of 35°, lining up northeast and southwest, and just clearing the approaches. Two scows with well-braced cribbing were floated under each arm and placed parallel to the channel, after allowing for the proper clearances at 207th Street. The suspended drum, etc., was braced and guyed to the adjoining scows. The weight was 900 tons, exclusive of cribbing, and the displacement of each scow was rated at 500 tons. (Fig. 1, Plate II.)

The scows had 4 ft. of water inside, and after the wedging and blocking up had been done, pumping was commenced by the aid of steam from four tugs, two lighters, and a boiler-scow. There were three 2-in. streams from the north and south scows, and two streams and an 8-in. centrifugal, from the other scows.

12.30 P. M.—The rim wheels were barely off the circular tread, and the tide had risen nearly 2 ft., as noted on the neighboring tide gauge of the Dock Department.

1.45 P. M.—The scows were 3 ft. out of water, and the depth of water in the hold was 1½ ft.

2.15 P. M.—The lower struts or arms to the rack (which had been sawed off) were clear, except at the west side, where much wedging and jacking was being done.

2.35 P. M.—All clear; the bridge drifted eastward, grazing first one approach and then the other.

2.45 P. M.—The lower struts cleared the southeast corner of the circular rack, and the tugs signaled "Go ahead." The bridgemen, being no longer needed at jacks, lines, etc., were relieved temporarily. Two tugs (each rated at 400 h.p.) were placed in front and two in the rear, and they were shifted about in going around the bend and approaching their destination. Full control was maintained through-

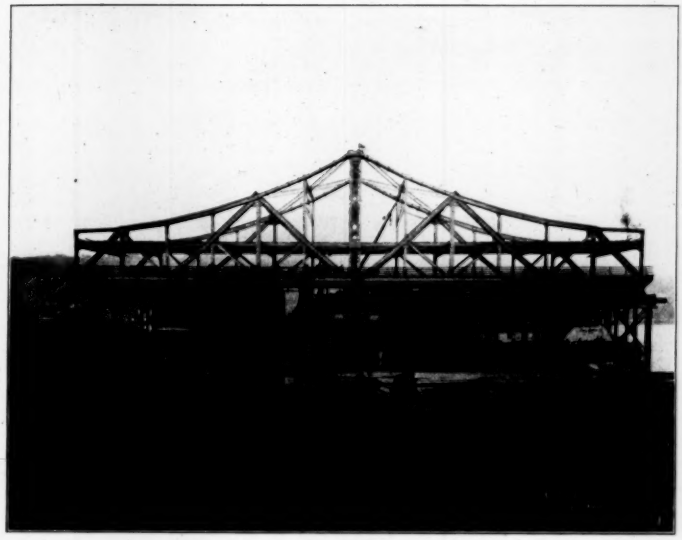

FIG. 1.—NEW DRAW-SPAN IN READINESS FOR MOVE TO BROADWAY.

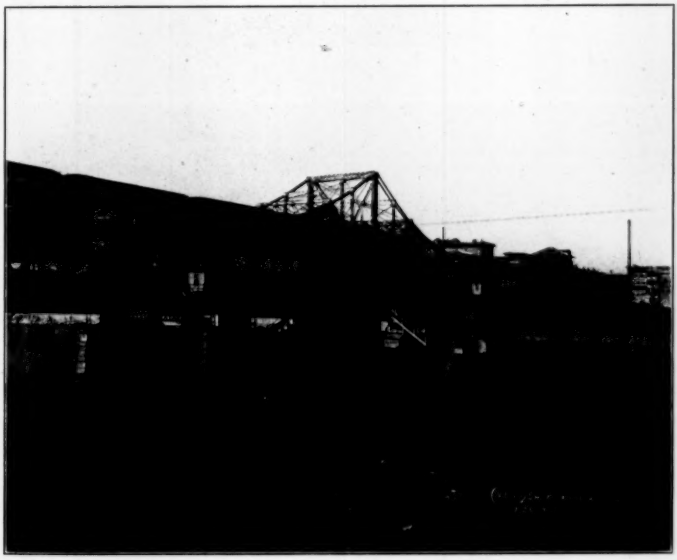

FIG. 2.—THE PRESENT HARLEM SHIP CANAL BRIDGE.

out the passage, the only incident being the considerable amount of mud stirred up at one point by one of the tugs. The writer was stationed on one of the middle scows. There was no creaking of the top chords, or other indication of strain in the main trusses. Some of the braces about the drum looked well "tuned-up," while the diagonals were taut. The cribs were solid and well connected. (Fig. 2, Plate II.)

3.45 P. M.—Arriving at University Heights, the various clearances were found to be sufficient. No bumping against the timber protection pier occurred. The diagonals to the drum slid past the round coping, and the rim wheels were well up over the rack, and, in fact, afterward, they raised somewhat. The pumps were again applied, and the tide soon helped to drop the mass on the pier. As the pivot casting drew near to place, the holes were seen to match, and the anchor-bolts were dropped in.

10.30 P. M.—The pinion engaged the rack, and, steam having been maintained all the way up from Broadway, the span was turned one-quarter around, and left in the open position above the pier protection.

*Moving the New Draw-Bridge.*—On the following morning (June 15th), the scows were taken to 216th Street and placed diagonally as before. The day was spent in adjusting the cribbing, calculating on the tides, as usual.

A finder-ring for the new pivot casting was placed accurately on the old pier, and wedge plates to relieve the pivot, were provided on its east and west sides. At the end piers, the latch girders and wedge plates were centered and trued up generally.

During the night rain began to fall and continued throughout June 16th, with the wind in the east. This had the effect of raising the low-water level 1.3 ft., and caused much delay in cribbing up. Later, the north scow grounded, in spite of this, showing the need of dredging, and causing further delay; so that, with high tide due by almanac at 6.40 P. M., it was 1.00 P. M. before pumping out began.

The plant was the same as before, with an added centrifugal pump and a number of hand-pumps. All were needed, for it was not until 4.15 P. M. that the pivot was clear, although the ends had been so for half an hour.

5.20 P. M.—The pivot was 10 in. clear of its seat, the latter being at Elevation 10.94 above mean high water. The top of the pier at Broadway was nearly the same (Elevation 10.89); but the wheel tread was about 1 ft. higher (Elevation 12.11), and this governed the lift at 216th Street, and the consequent time of starting. (Fig. 1, Plate III.)

5.55 P. M.—The pivot was 14 in. up, and there was not much more time, as the tide seemed to have turned. Tidal records showed that the flood tide was 0.4 ft. higher than usual. The order was finally given, and the immense structure (weighing with cribbing nearly 2 000 tons) was slowly pulled out into the stream, pivoting on the northwest corner and lining up, broadside to the north. The channel was none too wide, and there was some sweeping away of blocking into the river. One of the four tugs was detailed to butt out that corner, and thenceforth there was no stop or hindrance until near Broadway, where speed was reduced, lines were cast off, and the whole mass, grazing the approaches, was eased into its berth. The pivot casting slid over the rack with a margin of an inch or two.

6.35 P. M.—The casting, somewhat out of level, hung over the pier 15 in. clear, and there was ample clearance at the approaches. Lines were made fast, and the tugs were used, as before, to furnish steam for pumping water into the scows. The two scows at the north end were loaded heavily, the water being within 18 in. of the deck.

7.00 P. M.—Electric connections had been made, and lights were turned on below and above.

7.45 P. M.—The north pinion engaged the rack, and, later, closed the draw. The south pinion was evidently about right.

8.15 P. M.—Owing to the failure of a centrifugal pump, one of the northerly scows had to be sunk, and the pivot casting was 4 in. above the pier on the north side, and 6 in. on the south side, an inequality which was magnified greatly at the ends of the draw.

9.30 P. M.—The span rested on the center pier.

June 17th, 1906, Sunday:

12.30 A. M.—The scows had dropped down, and were free from the south arm. An hour later, the same was true for the north arm.

3.45 A. M.—The bridge was swung by hand-levers, and the end wedges were in place, but not adjusted.

5.20 A. M.—The span was swung half around by electric power, and it was found that it could be operated quickly and satisfactorily. The temporary wooden aprons were repaired, and the roadway was opened.

9.30 A. M.—Measurements at 68° Fahr. showed that the space between the draw and the approach span on the north side measured $2\frac{5}{8}$ in. and on the south side $2\frac{3}{4}$ in.

The next week was spent in shipping away timber, thereby releasing the scows, removing the chocks from the top chords, taking down the pile platform, adjusting the aprons, wedges, and pinions, installing the two circular feeder tracks at the pivot, and connecting with the third rails above. By the end of June, the approach spans had been lined up, and the rocker posts plumbed up. The asphalting was also well advanced.

It was decided to put in fixed aprons on the approach spans, and to close the span in one position only (without reversing), on account of the number of important rail connections. Later, it was found necessary to stiffen the rack with iron knees, at intervals.

Much of the new equipment was done by the Bridge Department of New York City, in accordance with its practice on the Harlem.

This is the only pivot-bearing draw on the river. The weight on the pivot is 1 500 tons. It is operated by two 60-h.p. electric motors, and, considering its weight, is handled more easily and quickly than any other. Occasionally, it delays traffic, while opening and closing, for a period of only 4 min. In addition to signals by whistle, and electric bells, there is a telephone connection (seldom used) between tower and engine-room. (Fig. 2, Plate III.)

During 1907 and 1908, the shafting was partially renewed several times, due to causes which were exceedingly difficult to locate, but resulting in twisting the shafting. In June, 1907, the latch girders were firmly fixed by reinforced concrete around and about them for the entire distance between the pedestals, and thus the play at the ends of the draw was much reduced.

The contract price for removing the old bridge and replacing it with the new one was about $250 000.

*Old North Approach Span.*—In November, 1907, the old north approach span, which had been left on the south bank, was rolled toward the river and received by scows, in much the same manner as described previously. The scows floated broadside through the draw channel, and were afterward swung around, with one tug in front and one in rear. The top of the east pier at University Heights was over-run comfortably, and the rollers did the rest. As no water was pumped into the scows, several tides were necessary before the final position on the masonry was reached (November 29th, 1907).

University Heights Bridge was declared open by Mayor George B. McClellan on January 8th, 1908.

In all these operations, extending over a period of two years, there was no accident of a serious character to any of the force employed.

The Rapid Transit Commissioners were represented by George S. Rice, M. Am. Soc. C. E., Chief Engineer, Alfred Craven, M. Am. Soc. C. E., Deputy Chief Engineer, Sverre Dahm, M. Am. Soc. C. E., General Inspector of Designs, and by C. V. V. Powers, M. Am. Soc. C. E.,

Division Engineer. The writer acted as Resident Engineer, and takes this occasion to make grateful mention of his subordinates, who continuously gave their best services. They were, from time to time, as follows:

Messrs. R. A. Berry, L. C. Devery, J. D. P. Hogue, R. J. Smyth, C. M. Torpey, and W. P. Vallely, Assistant Engineers; W. C. Martin, Rodman, and Theodore Belzner, Jun. Am. Soc. C. E., Inspector.

The Rapid Transit Construction Company was represented by George H. Pegram, M. Am. Soc. C. E., Chief Engineer, and A. S. F. Berquist, M. Am. Soc. C. E., Inspector of Steel.

## Historical Notes.

In searching for records of similar operations, the first, chronologically, of any magnitude, is seen to be the first in magnitude with reference to the tonnage moved, if not in regard to the velocity of the current and the exposure to gales; and, later, in relation to special appliances used in raising to place. This was the work of Robert Stephenson in connection with the Conway and Britannia Bridges, as recorded chiefly by his assistant, Mr. Edwin Clark.*

Mr. Stephenson had led up to those pioneer monuments by various achievements in his practice. He had acquired habits of close technical experimentation, and of co-operation with other engineers, architects, parliamentary committees, boards of directors, and, in fact, with men of all classes. He could say the right word at a dinner; as for instance when he noted the reduction of time between London and Dublin made possible by the bridges, and spoke of engineers as being instrumental in bringing about a better understanding between the English and the Irish.

It required a very able man to make the jump to the first long-span wrought-iron bridge; for, as Mr. Clark says, the process of uniting wrought-iron plates by rivets had been hitherto a peculiar feature of boiler-work or iron ship-building and had been little resorted to by the Civil Engineer, until Mr. Stephenson proposed the construction of these bridges.

All wonderful things cease to become so, however, when the separate steps are studied; and perhaps the transition from an iron ship, with

* "The Conway and Britannia Tubular Bridges." London, 1850, by Edwin Clark. Resident Engineer.

ribs and knees at short distances, to the rectangular tube, with web stiffeners and gussets every 2 ft., together with the cellular top and bottom, borrowed from a previous design of his, was not intrinsically so great an innovation, after all.

The spectacle of an accident to an iron vessel and the evidence of its stanchness in resisting the waves, and holding together, is said to have exerted a strong influence on Mr. Fairbairn, the manufacturer, and through him, on Mr. Stephenson, as to the ability of a similar iron framework to carry rolling loads.

Later, when the method of floating the tubes was considered, there naturally followed the idea of doing without the use of scows, but, for good reasons, that method was not adopted.

*The Conway Bridge.*—Work was wisely begun on the smaller bridge, at the Conway River (May, 1846), and, after two years of experiment and construction, the first tube was floated from its falsework, some 600 ft., to the site it now occupies.

Steam riveting machines had been used throughout, and half-round "rimmers." The type of tube had been decided chiefly from tests on a model of one-sixth the size of the bridge. Not satisfied with this, Mr. Stephenson supported the tube at its ends, cut out the falsework, and loaded it with cars containing iron plates. The resulting deflection was so small that no similar test was necessary again.

The floating of the tube (26 ft. high, 14 ft. wide, inside, 412 ft. long, and having a weight of 1 417 tons of 2 000 lb.) was done by six scows (each 98 ft. long, 25 ft. wide, and 8 ft. deep) arranged in two sets of three. This provided for an overhang at each end, sufficient to take the timber seats prepared in the recesses of the abutments, at some distance from the shore line. The tubes were 6 ft. 6 in. above the water.

There were two guide-chains under water, with which it was supposed that the movement could be controlled in a manner similar to that of a ferry on a suspended cable, but they proved almost useless, and most of the hauling was done by two Manila hemp cables, each operated from a 50-man capstan. The force was about 350 men, on land and water. A steamer was at command, but seems to have acted only as a utility boat.

Some progress was made against the rising tide, but more when it slackened at the flood, and enabled the tube to be easily hauled to place, clearing the abutments by 4 in. at each end. The average rise

of the tide was 18 ft. and the clearance of the bridge was also 18 ft., so that a lift of about 12 ft. remained to be made.

This was done by a hydraulic press (18-in. ram with a 6-ft. stroke) at each end.

The weight of the tube was transferred first to a cast-iron frame inside; thence to eye-bars with pin connections; and thence to the cross-head of the press above. A small steam engine and pump, to force water into the press, were attached.

Barring the pulling out of a cylinder head, and the delay in replacing it with a stronger one, the work was continuous; but cast iron was either eliminated or heavily reinforced with wrought iron at the Britannia Bridge.

Mr. Stephenson passed through on the first locomotive in April, 1848.

It may be well to note here the early decision with regard to painting plates before riveting them together, which was, that close contact is thereby prevented. The claim was made that old pieces of riveted work were most sound at the joints. Where necessary, a mixture of red and white lead was used as a filler.

The cellular floor and top chord, built up of plates and angles, were large enough to allow a man to paint them from the inside. The track floor was cheaply water-proofed with a mixture of coal-tar, lime, and turpentine. A corrugated, galvanized-iron roof was constructed over the whole tube.

The price per (long) ton was £37, and the total cost of the Conway Bridge was £145 200.

*The Britannia Bridge.*—The Britannia Bridge connects Wales and the Island of Anglesey, across Menai Straits. The two main spans are each 460 ft. in the clear, and were floated to place, whereas the approach spans were constructed on falsework at the site.

The Government required 105 ft. clearance above high water, and therefore a hollow, center tower, 220 ft. high or more, was required on Britannia Rock. The foundations were begun on Good Friday, 1846, and the last stone was laid in June, 1849, the masons working 12 hours a day for 6 days in the week, in order not to hold back the tubes. The latter were 30 ft. high, 14 ft. wide, inside, and weighed 2 150 tons.

In floating each tube 650 men were employed, about 400 being

sailors hired for the occasion. Eight scows were used, in much the same way as at the Conway Bridge, and were guided by Manila cables buoyed up by casks. Tarred Manila ropes were used for hauling, with "cable-stoppers" and "messengers."

The four tubes were handled in conformity with written instructions, after Mr. Stephenson had made experiments with models on a small pond. The various rocks and shoals were indicated, together with the scows, tubes, and lines, and everything that it was possible to foresee was discussed.

At the moving, he and others (including Captain Claxton, who had immediate charge) occupied a position on the top of the tube, and from that elevation signals by flags were given to each boat concerned.

Although, in floating the four tubes, there were instances of heavy cables snapping, and of severe bumps, yet, in general, the men were equal to the emergencies, and landed the tube each time in the recesses of the masonry, before the tide fell. Two steamers were in attendance.

The lifting machinery was considerably improved, the press having a 20-in. ram, lined with brass, and having a 6-ft. stroke as before. Leaks were stopped with oatmeal gruel and sal-ammoniac, and, later, by a second U-shaped leather collar below the first.

Brickwork in cement followed closely, but, in spite of this, the first tube, during one lift, dropped 8 or 9 in., doing considerable damage.

In the raising of each tube, 6 ft. per day was accomplished for about 16 days, and a single track was put in use in March, 1850. The fourth tube was floated in July, 1850.

The Britannia Bridge was riveted by hand. The total cost was £601 865, and of this, one-fourth was for masonry. Both the Conway and Britannia Bridges are still in use.

Associated with Mr. Stephenson were Mr. I. K. Brunel, and Captain Claxton; and as these gentlemen were soon afterward engaged at the Chepstow and Saltash Bridges, in similar movements, brief mention of these may naturally be made next.

*The Chepstow Bridge.*—The chief feature at the Chepstow Bridge (over the River Wye), barring the pneumatic process used in sinking the cylindrical foundations, was the design and erection of the 300-ft. channel span.

The top chord was composed of one wrought-iron tube, 9 ft. in diameter, treated like a trussed beam of three panels, except that there were two suspended chains, with the track between. The height of the truss was 50 ft. Pins 7 in. in diameter were used at the ends. A second tube for the other track enabled lateral bracing to be introduced, and stiffened each.

Following out the cautious method of the Conway Bridge, the first span was erected on falsework and tested with a live load of 2¾ (long) tons per linear foot. The wrought iron in each truss weighed 460 (long) tons. It was then taken apart, and the tube itself, supported by posts and chains, was floated (April, 1852), on six wrought-iron barges. It had to be done quickly, as the rise of spring tides was 40 ft. The use of crabs with two barrels enabled hauling-chains to be wound without difficulty.

The tube was lifted by jacks, during the day, some 40 ft., and, later, it was raised 50 ft. more, to its final position.

A single line was opened up in July, 1852. This was the first circular tube of large size introduced as a bridge member.

*The Saltash Bridge.*—In the Saltash Bridge, a single-track structure across the Tamar River, near Plymouth (also on the Cornwall Railway), the top chord tube was made elliptical (16 ft. 9 in. wide and 12 ft. 3 in. high). The bottom chord was double. The type of truss was a bowstring, with the string curved equally with the bow.

Mr. Brunel* (3d) states that "the mode of floating and lifting the superstructure had great influence in the preparation of the design" —meaning cylindrical foundations and cast-iron columns, as well as truss design.

There were two single spans of 455 ft., 56 ft. high, and each contained 1 200 tons of wrought iron. The bottom chord was of 7 by 1-in. bars, 20 ft. long. There was a solid ballast floor throughout.

The work was begun in 1853, but was delayed, on account of the difficulty of founding a 35-ft. cylinder, by using compressed air, at a depth of 88 ft. below high water. This was the first successful attempt on a large scale.

Meanwhile, the superstructure was manufactured, put together, and afterward tested at its falsework by a live load of 1 340 tons, uniformly distributed. The deflection was 5 or 6 in., and was deemed satisfactory.

* "The Life of Isambard Kingdom Brunel, Civil Engineer," by Isambard Brunel, B. C. L., London, 1870.

It was as late as September 1st, 1857, before the first span was moved, and information in relation to it is comparatively meager. The methods used at the Britannia Bridge were followed. The actions of the 500 men engaged were regulated in accordance with printed instructions which had been issued, and with flag signals from the "bridge," where Mr. Brunel and others were stationed during the passage. Mr. Stephenson was too ill to be there.

The move was at first outward from the shore, then, after an interval in which the hawsers were shifted, up the river, endwise to the center pier, then a quarter turn was made, and finally, an accurate placing by strong lines at the piers. There was a clearance of a few feet above the water. The tide was not swift and there were no mishaps mentioned.

The lifting was done 3 ft. at a time, separately at each end. At the center pier, cast-iron columns (braced) were built up as fast as these lifts were made; but, at the shore end, the masonry proceeded more slowly. There was no cause for hurry, as the river traffic went through the other opening. There was finally a clear distance of 100 ft. above spring tides; and the total height above the foundations was 260 ft. to the highest point of the trusses.

Three hydraulic presses or jacks were used under each end. The rams had a screw-thread, arranged with a nut in such a way that the tube was supported at all times. Timber packing was also used. By July, 1858, the full height was reached. The second span was floated successfully soon after. In May, 1859, the bridge was declared open by Prince Albert, after whom it was named the Royal Albert Bridge. The total cost was £225 000. The fiftieth anniversary has recently been celebrated, the old bridge remaining as it was originally.

*Other Bridges.*—Passing by well-known examples of this method of erection—the Moerdyck Bridge (1875), the new Tay Bridge (1885), the Hawkesbury Bridge (1889), and others of 500 tons or less, in which about the same or similar principles were involved—we come (1890) to the 523-ft., single-track, through bridge across the main channel of the Ohio River, below Pittsburg, on the Ohio Connecting Railway (Pittsburg, Cincinnati, Chicago, and St. Louis Railway), erected by the Keystone Bridge Company, C. L. Strobel, M. Am. Soc. C. E., Chief Engineer.

The Government, having required the long span and also a clear

height of 75 ft. above mean water level, and having limited the time during which the river might be obstructed, it became necessary to build the falsework at a corresponding height, assemble and erect the bridge upon it, and then float the structure to its site, as quickly as possible.

Nineteen bents of 5 piles each were driven and cut off 16 ft. above the water. On these were framed bents of 5 posts each, with an 80-ft. sill and a 32-ft. cap, all with the usual railroad trestle dimensions. At the base, across each alternate bay, 20-in. I-beams were added. Under these were duly placed nine ordinary coal barges (130 by 26 by 8 ft.).

The weight of the bridge was about 900 tons. The trusses were 65 ft. high. The bracing of the bents into towers and the binding of them together by rods with turnbuckles was susceptible of careful study, and, once accomplished, eliminated the principal cause of uncertainty. At Hawkesbury, the Union Bridge Company had effected this by a single pontoon, 335 ft. long, well braced with timber and wire cables internally, but with the superstructure at a much lower level. In both cases, the hauling to place was done by cables.

At Pittsburg, two scows were fastened to the bows of the end barges (leaving the three barges in the middle unattached), and on these scows four engines controlled the lines up to the bridge piers. The nine barges were braced together at the bow, and, after floating out to clear the piles, they were braced likewise at the stern. The current in the river was slight, and, although a couple of heavy showers occurred while the scows were being moved the few hundred feet necessary, there was no bumping against shore or against obstructions.

The itinerary of the work was as follows:*

8.50 A. M., August 19th.—Sufficient water had been pumped from the barges so that the mass rested on them.

11.15 A. M.—The barges had been floated out toward the center of the river, thereby clearing the bents of piles.

7.30 P. M.—Water was again admitted to the barges, and the span cleared the bridge seats by 2 ft.

8.20 P. M.—The span was about 9 in. clear. The work was blocked up and left until the following morning.

7.30 A. M., August 20th.—The lowering was continued, so that the bridge rested on its piers. The barges were removed later in the day.

* *Engineering News*, September 20th, 1890.

There had been no distortion of bents or barges, nor any important casualty of any kind.

In Canada, the Dominion Bridge Company has erected several bridges of note, in this manner.

The Coteau Bridge (1890), across the St. Lawrence (Grand Trunk Railway) west of Montreal, has single-track spans of 175 to 223 ft.

The Shubenacadie Bridge, in Nova Scotia (1901), across an arm of the Bay of Fundy (Grand Trunk Railway), has single-track spans of 215 ft., each weighing 150 tons.

The Miramichi River Bridge, Newcastle, N. B. (1902), has single-track spans of 204 ft., each weighing 320 tons.

The French River Bridge, Ontario, a single-track span of 415 ft. weighing 1 424 tons, was erected by the Canadian Pacific Railroad in 1907. This was slid endwise from the embankment upon a scow (155 by 33 by 12 ft.) and thence was hauled to place by lines from an engine on the scow.

Local difficulties in all these cases were overcome successfully.

*Sand Jacks.*—The use of sand in jacking up or in letting down bridges of moderate tonnage dates back to 1878, or even earlier, in Europe.

The most noteworthy instance of this sort in America was witnessed by the writer on Sunday, December 20th, 1903, at Newark, N. J., when the 220-ft. double-deck draw-bridge of the Delaware, Lackawanna and Western Railroad, across the Passaic River, was moved, complete and ready for use, to its present position, under the direction of Lincoln Bush, M. Am. Soc. C. E., Chief Engineer. The bridge is center-bearing, and has four tracks. It was moved up stream some 40 ft. and lowered 10½ ft. from its level at the old pier.

Several years before, it had become necessary to renew the old draw, and as grade-crossing work was in progress in the vicinity, the new draw was designed accordingly, and the lower deck used temporarily.

The weight of the bridge was 1 017* tons, and the sand and timberwork 936 more, a total of 1 953 tons on the scows above the deck.

A year or so before, there had been experiments on the action of sand in compression by loading two 83-ft. girders on a pair of plungers

* *Engineering News*, Vol. 50, p. 596.

fitting into 4 by 6-ft. boxes. It was found that there was little swelling, that the most favorable angle of the side holes was 45°, and that the holes should be made funnel-shaped, with a diameter of 2 in. inside and 3 in. outside the box. There were also 2-in. holes in the bottom of the box. All holes were regulated by slides.

The bridge rested on two scows under each arm, and there were four sand boxes of 12 by 12-in. stuff, each 52 ft. long, 12½ ft. high and about 4 ft. wide, inside measurements. The plungers had a clearance of ½ in., and their pressure on the sand was less than 1½ tons per sq. ft.

The rise of tide at Newark is generally somewhat more than 4 ft. but on the day the bridge was moved the wind and tide were perverse, and, unfortunately, there was a rain all day; so that it was with difficulty that the sand was kept in prime flowing condition, tarpaulins being used to protect it as much as possible.

In spite of all precautions, there was irregular settling, and time was lost in balancing the movement. The bridge had been raised by the tide, helped by four centrifugal pumps. A boiler scow and pump was held in reserve. The rate of movement was as follows:

At 6.30 A. M., the old supports were cleared,
" 9.35 A. M., began lowering at the new site,
" 5.00 P. M., the span rested on the new pivot,
" 6.15 P. M., all scows had been released,
" 8.30 P. M., the first train crossed over.

The objection to this method is the likelihood of wetting the sand (which in this case was screened through a sieve of ¼-in. mesh) and the consequent ignorance as to what is going on inside the boxes. Under such conditions, looking for evidence of strain in heavy timber is a responsibility which few engineers would care to take.

Finally, other flotation operations on the Harlem River should be mentioned, namely: At Macomb's Dam Bridge, at Madison Avenue, and possibly at the crossing of the New York Central and Hudson River Railroad—operations which deserve to be recorded in detail.

# DISCUSSION

LINCOLN BUSH, M. AM. SOC. C. E. (by letter).—In reference to the use of sand jacks for lowering the draw-bridge of the Delaware, Lackawanna and Western Railroad over the Passaic River at Newark, N. J., on December 20th, 1903, the following comments are offered: Mr. Bush.

On the day the bridge was moved and lowered, rain commenced at 1.20 A. M., and continued until 5.00 P. M., at which time the bridge rested on the new center pier in exact position, the precipitation during this time being 1.23 in. In order to keep the sand dry while the sand boxes were being filled and for the same purpose after they were filled, tarpaulins had been provided before the operation. During the night prior to the move, one of the tarpaulins accidentally became partly removed on the south side of one of the four boxes, letting some water into the sand near the top of the box. This wet sand, however, caused a delay of only 20 min. in the lowering, and, aside from this incident, there was not the least difficulty in keeping the sand dry, even with the heavy precipitation of 1.23 in.

Mr. Howe mentions the irregular settling and lost time in balancing the movement. He probably refers to the lowering of one end of the bridge at a time, which was done in 2-ft. stages. The day was chilly, and the men were wet to the skin. The writer was reasonably certain that the operation could be completed on schedule time, by handling the lowering slowly and carefully, rather than by seeing how quickly it could be done, and, instead of lowering both ends of the bridge at the same time, he adopted the plan already mentioned. It was shown by tests made with test sand boxes, and in the actual lowering of the bridge itself, that the bridge could be lowered very readily at the rate of 3 in. per min.

Observations on the tide movements at the bridge site for four months, and other reliable data, showed that at times the minimum low tide did not fall below zero or mean tide, and that the maximum low tide frequently fell to an elevation of 3 ft. below mean tide. These data also showed that at times the high tide did not go above mean tide, and that the maximum high tide at times rose to a point 4 ft. above mean tide. These observations showed that the minimum variation between high and low tide was nothing, and that the maximum variation was 7 ft. The normal variation for low tide at the bridge site is —2.5 ft. (below mean tide), and the normal variation for high tide is +2.5 ft. (above mean tide).

The work had to be done, as planned, in 12 hours, in other words, from low tide to low tide. When the four barges were run under the bridge, the low tide was —1.9 ft., and when they were released at the next low tide, fell to only —1 ft. instead of a normal low tide of

Mr. Bush. —2.5 ft. The high tide rose to +3.0 ft. instead of a normal high tide of +2.5 ft.

The tests made with test sand boxes showed, with most convincing evidence, that dry sand, carrying a load of about 2 500 lb. per sq. ft., produced very little lateral pressure; and no outward deflection of the timber, with a straight-edge on the sides of the boxes, was discernible. Neither was there any perceptible deflection in the sides of the timber boxes used in lowering the bridge, except with one box where wet sand occurred, and, as stated, this was relieved with a delay of only 20 min. by opening the sand holes lower down in the box where dry sand flowed out freely.*

The fact that the work was done on schedule time, as planned, with abnormal tide conditions and a heavy rainfall continuing throughout the operation, should be convincing evidence that this method of lowering a heavy structure, tempered with good judgment, is perfectly safe, economical, and efficient.

Mr. Gay. MARTIN GAY, M. AM. SOC. C. E.—When the proposal was first made to run the trains of the Rapid Transit Railroad across the Harlem Ship Canal Bridge, it was thought feasible to add an upper deck to the old draw-span and to build new spans above the old approaches.

This was objected to by the Department of Bridges, under the jurisdiction of which the bridge came, on the ground that the turntable, though well designed and sufficient to carry its comparatively light load of some 700 tons, was not substantial enough to endure the racking and distortions due to a moving load of perhaps twice that weight.

While this point was under discussion by the engineers of the Department of Bridges and the Rapid Transit Commission, several other interests came into view. For some years the Kingsbridge Railroad Company had held a franchise permitting it to cross the bridge, and its officers had discussed the question with sufficient seriousness to cause the Department of Bridges to make a study of the situation and to determine that it would be necessary to strengthen the floor system and practically rebuild it at a higher elevation, and also to change the grade of the approaching streets. This would have been a matter of considerable expense.

Also, the New York Central Railroad, in connection with the plan for the elimination of grade crossings, had prepared to abandon the long curve with many crossings through Kingsbridge Village, and to cross from the east bank of the Harlem River to the east bank of the Hudson, following the north bank of the Ship Canal and passing under the Ship Canal Bridge. To do this an additional space of 12 ft.

*An accurate and full presentation of this operation and the tests made prior to it are given in *Engineering News*, December 31st, 1903.

was required between the bulkhead of the canal and the north abutment of the bridge. Mr. Gay.

Also, at this time the Department of Bridges was planning a new bridge across the Harlem, near Fordham Landing, and had about determined to build a double-leaf rolling lift of the Scherzer type.

It was to the combination of these various interests that we owe this admirable paper. Each party to the combination contributed its share of the cost of the project, either in money or in work, or both, and each got what it wanted.

Mr. Howe has described the work of moving the bridge so clearly that little can be said on that head.

Each of the six operations, that is, moving out an old span or moving in a new one, was not of itself a very complex problem, but, taken altogether, it was a work of considerable magnitude, and considering the cramped space in which the contractor was obliged to maneuver the approach spans, the uncertainty of the tides, and the short space of time during which he could obstruct travel, the problem was one requiring nice calculation and unusual judgment.

The time during which street travel could be obstructed was fixed by the Department of Bridges, whose duty it was to consider the convenience of the public, after consultation with Messrs. Terry and Tench, as to the methods they proposed to use and the time they would require. The Department was not willing to deprive people of an opportunity to cross the stream for a longer time than necessary, and did not wish to impose oppressive conditions on the contractors.

It was estimated that one day would be sufficient to move and readjust each of the approach spans, allowing for accidents and delays, and that 3 days would be required for the draw-span. Therefore, the permit allowed street travel to be interrupted for a total time of 5 days, but not for more than 3 days consecutively. That no very serious delays occurred is indicated by an analysis of Mr. Howe's figures, which shows that the total time of interrupted travel was 3 days, 16 hours, 35 min., and that during the moving of the draw-span, the interruption was less than the stipulated 3 days by 4 hours, 55 min.

Each of the three new spans was put to use by vehicles and pedestrians as soon as it was placed in position, and the draw-span was opened to pass vessels without causing any delay to river traffic.

The old spans, which have become a part of the University Heights Bridge, had to have considerable changes in order to bring them up to modern requirements, and they have done duty continuously since the formal opening of the bridge.

In all operations of this nature on the Harlem River, of which there is any record, the rise and fall of the tide has been counted on as a factor and has been used to some purpose, and yet it is such an uncertain factor that in almost every case, other means for raising or

Mr. Gay. lowering have been provided and usually resorted to, in order to supplement the deficiency of tidal power. As the movements of the tides, of greater or less extent, take place at more or less definitely known times, they must be reckoned with. On a non-tidal stream, however, where other power would of necessity be provided, the attendant uncertainty and anxiety regarding the behavior of the tide would be eliminated, and probably the cost would not be greatly increased.

One occasion on which the lifting power of the tide was used to good advantage, but perhaps not with any great economy, was in the moving of the draw-span of the old Macomb's Dam Bridge, of which Mr. Howe has spoken. The bridge was built in the early Sixties, and was replaced in 1892 by the present structure, which was designed and the construction supervised by A. P. Boller, M. Am. Soc. C. E. It was necessary to remove the old bridge to make way for the new one, and it was also necessary to provide for public travel. It was decided, therefore, to move the draw one block north of the old site, to the line of 156th Street. A pivot pier and approaches having been constructed at an elevation 12 ft. lower than that of the bridge, the problem was to move the draw-span about 200 ft. north, and to lower it 12 ft. to its new position without obstructing navigation. This was done by lifting the span on two scows and a cribbing of 12 by 12-in. timbers, and towing it to a pile and cribbing pier which had been built near the bank of the stream and out of the course of passing vessels.

Here it was deposited safely at an elevation somewhat lower than that from which it had started. When the next flood tide raised the scows and bridge, a course of crib timbers was pulled off the pier, and as the span settled with the ebb tide and rested, a course of crib timbers was taken off the scows. As the next flood tide freed the span from the pier, another course of timbers was removed and so on, until it rested at the proper elevation to be floated across to the permanent pier and be placed in position.

An instance of the tide not doing its duty, as expected, was at the moving of the Madison Avenue draw-span, where an east storm made an early flood which caught and held the scows under the span after it had been landed. Considerable damage might have resulted, but for the scuttling of one of the scows.

Mr. Clarke. ST. JOHN CLARKE, M. AM. SOC. C. E.—As Mr. Gay has mentioned a design prepared for this bridge, in which parts of the old bridge were used, it may be of interest to explain more fully the reason for making this design.

When the crossing of the Harlem at this point was being considered by the engineers of the Rapid Transit Commission, it developed that the Bridge Department desired a wider bridge, and also wanted to use the old bridge at the lower crossing; that the New York Central wanted to change the northern span, so as to give more head-room

and also room for more tracks; and that the Metropolitan Street Railway Company was considering a change in the floor system of the old bridge, so as to provide a slot and conduit in order to allow the surface cars to cross the bridge and continue up Broadway. Changes in the old bridge for any one of these interests would have been quite expensive; but to provide for these several requirements in a new bridge would not add very materially to its cost. Mr. Clarke.

The stand was taken by the other interests that the Rapid Transit Commission, or rather its contractor, had to build a new bridge in any case, and that, while doing so, it would be better to provide for all future uses of the bridge, the additional cost being small. It is hardly necessary to add that these interests displayed no great willingness to assume a fair share in the cost of the new bridge.

It was because of this condition of affairs that the speaker, as General Inspector of Designs, considered the possibility of using the old bridge. A design was prepared utilizing the floor system, turntable, and machinery, with the bottom chord of the old draw, new and deeper trusses being provided. This design complied with all the theoretical requirements of the Bridge Department, and it was shown that the old bridge could be altered to serve the Rapid Transit Railroad. When this was evident, and not before, it became possible to make a fair arrangement with the various interests involved. The new bridge was designed, and all those using it contributed to the cost.

All were somewhat disappointed because the design for using the old bridge was not adopted, as it seemed hardly fair to these plans after they had served their purpose so well.

THEODORE BELZNER, JUN. AM. SOC. C. E. (by letter).—The writer was connected with the construction of this bridge as Inspector of Erection, for the Rapid Transit Railroad Commission, and recalls the cracks which were discovered at the apex of the connecting angle plates, and during the riveting up of those replaced. In a general way, he tested the shop rivets of the connecting plates at the other end of the pivot girder, in order to determine their tightness as compared with the field-driven rivets, and found quite a number of the shop rivets loose. This was reported to Mr. Howe, and resulted in a conference between the engineers and inspectors. It was finally decided to cut off a few rivet heads and drill out the shanks. This method of removal, however, was abandoned after a few rivets had been partially drilled out, as it was slow and costly, and in some cases it was difficult to keep the drill centered on the rivets, especially on the innermost ones. Then the rivets were "backed out" and with much better results, on account of the reamed holes in the plates, etc. Mr. Belzner.

On May 15th, 1906, the writer reported the results of his examination to Mr. Howe, which in part was as follows:*

* *Transactions*, Am. Soc. C. E., Vol. LVII, p. 262.

Mr. Belzner.

"The bent plate of this member contained 87 long 1-in. shop rivets, 28 of which were condemned for looseness. The shop rivets were cut out and replaced by machine-driven field rivets. In cutting off the heads and 'backing out' the rivets, no material damage was done to the adjacent ones, but many of them became loosened while the field rivets were being driven. The rivets 'backed out' easily, some requiring only a few blows with an 8-lb. hammer. An examination of these rivets showed that they had not been upset properly, in some cases shoulders were formed under the heads (caused by oval-shaped holes through the bent plates), in other cases the rivets were slightly rusted and showed some scale. The result was that more than 60 field rivets had to be driven to replace the shop rivets."

Referring to the twisting of the shafting of the New Ship Canal Bridge, the writer would like to ask if this occurred in driving home the wedges on the rest piers?

If the writer remembers correctly, there was a slight "tilt" at the southeast corner of the bridge, and some difficulty in driving the wedges, especially at this point. Information as to the adjustment of this matter would be of interest.

How does the efficiency of the shaft claw couplings compare with that of the flanged ones?

Mr. Skinner.

FRANK W. SKINNER, M. AM. SOC. C. E. (by letter).—The operations described in this paper are nearly or quite the most intricate and prolonged of any of similar character yet effected, and their complete success under difficult and involved conditions reflects great credit on the engineers and contractors for the preparation of the plans and for their courage and ability in executing them.

The author's description of the moving of this bridge is so complete that there is no room for criticism or discussion, but some additional facts concerning other work of a similar nature which he mentioned briefly, may be timely.

The Hawkesbury Bridge, Australia, has seven through, double-track spans which were erected successively on falsework, 34 ft. high, on the deck of a 61 by 335-ft. pontoon, 10 ft. deep, stiffened by bulkheads and trussing cables, and sunk on a timber grillage in shallow water. After the completion of each span, the water was drained out of the pontoon at low tide, and at high tide it was hauled to the piers, a distance of about 4 000 ft., by two cables operated by fixed hoisting engines. Each span was lowered to the piers by admitting water ballast to the pontoon. Despite several accidents, such as the breaking of the cables, the grounding of the pontoon, and the reversing of one span, the erection was accomplished successfully.

The single-track bridge across two branches of the Miramichi River, New Brunswick, had twelve 204-ft. spans, each weighing about 225 tons. Without much interruption of traffic, these were replaced, on the same piers, by stronger 270-ton spans. Two sets of pile false-

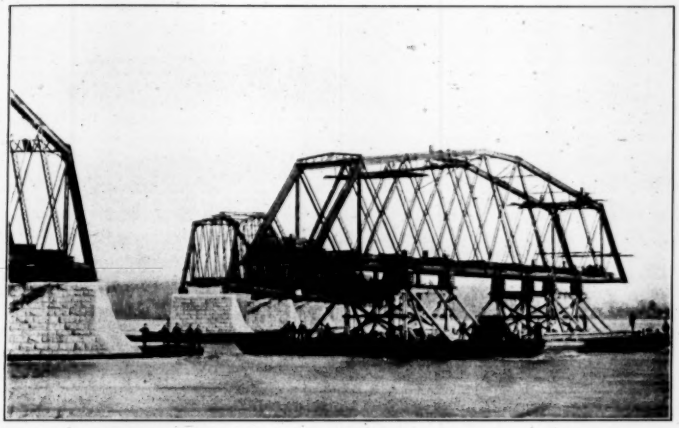

FIG. 1.—COTEAU BRIDGE. FLOATING LAST SPAN INTO POSITION.

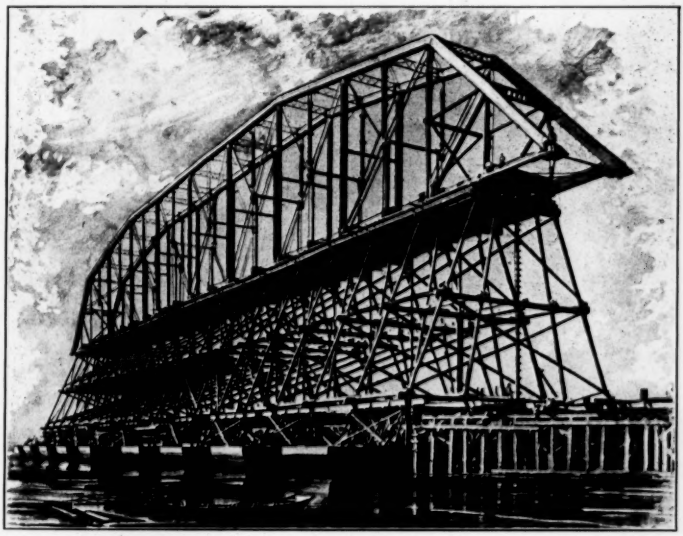

FIG. 2.—BRUNOT ISLAND BRIDGE ACROSS THE OHIO RIVER. COMPLETED SPAN AND FALSEWORK FLOATED ON NINE BARGES.

work, opposite each other, were established parallel and close to the old bridge, and the new spans were erected successively on one of them, skidded across to the other, and riveted up while the next span was being erected on the first falsework. After the riveting was completed the span was transferred to towers on the decks of a pair of pontoons, and was towed to position between the piers. Simultaneously, the old span was lifted from its piers and removed on a Howe truss span on the decks of two other pontoons. In some cases the old spans were deposited on trucks on falsework, rolled ashore, and dismantled at leisure; in other cases they were deposited on piles driven in the river and there taken apart with an ordinary traveler. The spans were replaced with an average interruption of traffic of about 4 hours. Mr. Skinner.

The Coteau Bridge, across the St. Lawrence River, has 14 spans about 220 ft. long. These were erected successively on shore falsework about 3 miles up stream from the site, skidded to towers on the decks of a pair of pontoons trussed together, safely towed down through a 7-mile current, and deposited on their piers.

The Midland Railway crosses the Shubenacadie River, Nova Scotia, at a point where it is subject to a 32-ft. rise of the tide. The current is very swift, and the bottom under three of the 215-ft., 330 000-lb. pin-connected-truss through spans was too soft to support falsework; therefore these spans were erected on pile falsework at right angles to the bridge axis, transferred to towers on a pair of pontoons, and hauled to position by hoisting engines located on the bridge piers. Each span was transferred from the falsework to its permanent position in less than 2 hours.

The 232-ft. span of the Fraser River Bridge, at New Westminster, British Columbia, has two trusses 54 ft. deep, 20 ft. apart at one end and 135½ ft. apart at the other. These were erected successively on falsework in the river near a completed span of the bridge. The first truss was moved transversely to a temporary support on falsework piers, and the second truss was erected and braced to it; the heavy floor-beams and transverse struts were assembled, and the 468-ton span was transferred to three large pontoons, floated on them to position, and lowered to its bearing on its three permanent piers.

Other bridges floated to position in America, are the Belle Isle Bridge, Detroit, eleven 156-ft. spans of which were erected on shore and towed nearly a mile to the site; several draw-bridges; and the Harvard Bridge, Boston, with 23 spans ranging from 76 to 106 ft., the separate girders of which were delivered by a gantry crane to a large scow, towed to position, and lowered to their piers by admitting water ballast and by the falling tide.

The anchor arm of the long-span Interprovincial Bridge, across the Ottawa River, and the Faidherbe Bridge, in Africa, were ereceted

Mr. Skinner. on falsework supported on boats, and the Bismarck, Omaha, and Glasgow Bridges, across the Missouri River, were all erected or replaced on falsework trusses which were moved from pier to pier on pontoons.

Mr. Howe. HORACE J. HOWE, M. AM. SOC. C. E. (by letter).—In comparing old and new methods, the advance is found to be along these lines:

*First.*—The use of well-bonded cribbing, in preference to framed bents on the scows;

*Second.*—The supply of abundant steam for pumping water in and out of the scows, thereby neutralizing any uncertainty as to the tide;

*Third.*—The use of tugs of ordinary size;

*Fourth.*—The use of improved hydraulic jacks or presses, for adjustments;

*Fifth.*—The use of sand jacks for loads of 2 000 tons or more, under particular circumstances.

The writer thinks that much might have been said in the discussion as to the last two headings.

When one calculates the cost of the time frequently wasted by a high-priced gang of men, on account of defective judgment as to jacks, and compares this cost with the rental of adequate power, he is led to think that here is a new field for the engineer.

Mr. Bush has taken a step ahead, in this respect. He also is in line with Mr. Stephenson and others in informing himself by previous experiments on a generous scale of what might reasonably be expected; and furthermore, in allowing generously for contingencies of all kinds during the critical period.

Mr. Gay's experience with the Harlem, and his proximity to the work described, render his opinions of especial value. His estimate of the loss of time to the traveling public at the bridge proved to be nearly exact.

Mr. Clarke's design, it is needless to say, involved expert work of a high order. As one examines the bridge to-day, he is struck with its difficulties, and furthermore of the subsequent difficulties of impressing opposing interests as to its practicability.

The writer would call Mr. Belzner's attention to the quality of the hand riveting of Mr. Stephenson's time, superseding, in fact, the steam riveting at Conway.

To-day, it would be quite a question how long it would take a power-riveter to become as truly expert at hand-riveting as one of those old-time riveters. Attention is also called to the avoidance of painting the plates before riveting, and the use of red and white lead as a filler, both practices being in line with the writer's experience.

As to the twisted shafting, probably more work was done at that corner by the wedges, in lifting the bridge, due to slowness of action relative to the other wedges. The bridge seats are known to be level.

Mr. Howe.

The writer is informed that the "clutch" couplings have worked satisfactorily. On a draw-bridge subject to deflections and vibrations, there seems to be a certain amount of "give" necessary to a line of shafting.

The writer is indebted to Mr. Skinner for his illustration of the classic falsework used at the Brunot Island Bridge, and for his other references, bringing the subject substantially up to date.

AMERICAN SOCIETY OF CIVIL ENGINEERS
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TRANSACTIONS

Paper No. 1144

# PRECARIOUS EXPEDIENTS IN ENGINEERING PRACTICE.*

By John Hawkesworth, Assoc. M. Am. Soc. C. E.

With Discussion by Messrs. Eugene W. Stern, W. W. Crosby, J. S. Branne, Andrews Allen, Guy B. Waite, J. H. Gandolfo, and John Hawkesworth.

In presenting this paper for the Society's consideration, the observation may be made that it is not, in the strict sense of the term, a scientific paper. It would seem, however, that if engineers had no thoughts or aspirations in regard to their Profession, other than those applying to technical details, that Profession, and the Society which represents it, would fall short of the standards which inspire workers in other fields. In the many scientific papers which are continually being presented, attention is directed to methods and formulas by which one may build safely and efficiently. With these two watchwords of the Engineering Profession—"safety" and "efficiency"—is it not necessary to class the additional word, "honesty"? In the Engineering Profession, as in other professions, ordinary intentional dishonesty sooner or later brings its own punishment. It is not to such self-evident facts that the writer would draw attention.

There is another kind of dishonesty to which one may, without premeditation, be made accessory, which is known to every engineer and architect, yet very rarely discussed. Possibly this is because some may believe it is the result of the present method of financing large

* Presented at the meeting of February 16th, 1910.

construction work, others that it is caused by undue competition among contractors; and there are a few who pessimistically declare that it is simply a part of the ever-increasing laxity of moral standards in all fields of industry. Whatever the cause, the writer's object is to expose the facts relating to the use of certain precarious expedients, and to hint at a possible remedy. It is hoped that the presentation of this paper to the Society, and not to the public press, will demonstrate that it is not intended as a "muck-raking" article. The evil lies within the circle of knowledge of professional men, by whose efforts alone it can be eradicated.

Let it be assumed that some large piece of work—a public library, a railroad terminal, a hospital, a power-house, or a municipal pumping station—is to be constructed. As either an engineer or an architect may be engaged to take supreme charge of the design and construction, he will be referred to herein as the "designer." The "designer," then, having received his appointment, proceeds with the preparation of his plans. Now, if he be an architect, his specialty will take form in the artistic embellishment and utilitarian arrangement of his design. Rarely will he have, either from his own knowledge or from that of his office force, the qualifications necessary to the economic design of all the other factors, such as structural computation, economic lay-out of heating and lighting, sanitary arrangement of plumbing, and the like. To be sure, some of his assistants, or even he himself, may be able to do one or two of these things as well as specialists, but seldom all of them. If a structural engineer is the "designer," then that feature of the work, and perhaps one or two others, will receive the fullest emphasis, to the possible detriment of the architectural or mechanical side.

Now, occasionally, the "designer" calls to his assistance specialists in each of the departments with which he (or his office force) is unfamiliar. Their fees are usually higher in proportion than that which the "designer" himself is to receive, and must be paid out of his own pocket. Also he or some of his assistants soon acquire that "little learning" which is "a dangerous thing," and begin to believe themselves capable of doing the specialist's work on future occasions. These two reasons militate against this solution of the problem.

Next in order comes the method which the writer believes is used in the majority of cases, where the work involves a number of radically

different specialties. The "designer" prepares his plans and specifications, in complete form as far as his knowledge carries him, tentatively on the points where that knowledge is lacking. Then, whether it be the problem of reinforced concrete design, or heating, or lighting, or what-not, he allows some of the contractors, who have been importuning his office with this very object, to examine his tentative plans and make suggestions for increasing their efficiency and practicability. Of course, there is opportunity here for the ordinary, intentional dishonesty heretofore referred to, such as the insertion in plans and specifications of some privately controlled or patented device, the stone from some particular quarry, or the like. However, it is assumed that the "designer" is not intentionally dishonest, and that he will listen to no suggestions of this kind.

In accepting the services of these contractors, he expressly stipulates that he is thereby placed under no obligation to them, and that he accepts or rejects their recommendations as to changes in the design with precisely the same freedom that he would had he called in consulting experts. The difference consists in the fact that he has not had to pay over a large proportion of his fee.

According to the usual custom, the "designer" receives half his total fee upon completion of the working plans and specifications. This is almost always exhausted by his office expenses up to this point. His profits lie in what is left of the second half of the fee, after deducting his expenses for superintending the actual construction. Should the work not be built, for any reason whatsoever, the "designer" would not receive this second half of his fee. Small wonder, then, that he is reluctant to pay out of his own pocket for specialists, at a time when the ultimate financial outcome to himself is still in doubt.

Returning, now, to the contractors, it is found that in the case of work being planned for private individuals or corporations, they have frequently secured from the owner letters of introduction to the "designer," which cannot be ignored; but, in most cases, those kind-hearted gentlemen, the contractors, carry their competitive methods right up to the point of trying to excel each other in doing the greatest amount of work for nothing. They are ready to furnish samples of brick, stone and mosaic, working models of hardware and plumbing devices, cartoons of ornamental terra-cotta, designs of reinforced concrete and ironwork, lay-outs of heating lines or electric wiring, or to

pass upon and revise the "designer's" embryonic drawings and specifications on any of these subjects.

Do not let it be forgotten that the "designer" intends to be absolutely honest. He warns these contractors, from whom, on one point or the other, he has accepted advice or assistance, that he will not permit the introduction of exclusively controlled devices, and that the general contract is to be given to the lowest bidder, irrespective of all else. If a municipal job, bids will be advertised for; if a private one, the list of contractors invited to bid will be long enough to render favoritism impossible. Does this discourage the contractor who is giving time and thought, which means money, to the details of his own specialty on the general plans in the "designer's" office? Not in the least; he works hard, constantly changing his lay-out, in whatever line it may be, to suit the general scheme as it evolves from the "designer's" mind. Furthermore, his work and his recommendations are honestly rendered, and about as efficiently as that of the high-priced specialist whom the "designer" might have engaged. Also, the contractor who is allowed to render this assistance never leaves out anything, nor—and this should be well noted—does he call attention to anything superfluous that may exist in the tentative lay-out prepared by the "designer."

Now pass to the time subsequent to the receipt of bids from the general contractors. These bids, which are in each case the aggregation of lowest prices received by the general contractor from various sub-contractors, added to his estimate for that portion of the work which he will do himself, are honestly rendered. The contract for bridge, or library, or power-house, or whatever it may be, is usually awarded to the lowest responsible bidder, who then becomes the general contractor.

For the proper execution and construction of the work, it is usually found necessary to insert in the specification that the general contractor's selection of sub-contractors shall be subject to the approval of the "designer," and, in some cases, of the owner also. The general contractor presents his list of "subs," and on this list are almost certain to be found some of the very men who rendered aid, in one way or another, to the "designer." If for no other reason, they are on the list because their estimates to the general contractor were the lowest which he had received. Though he be the most honest man in the

world, the "designer" cannot help giving his consent to the employment of these sub-contractors, for two legitimate reasons: First, he is reasonably sure of their ability to perform their particular work satisfactorily, or he would have had nothing to do with them in the first place. Secondly, their intimate prior knowledge of the plans and specifications renders it likely that they know the requirements of the job. Another reason is the fact that sometimes the owner may indicate his desire to have these very sub-contractors approved, unless the "designer" can offer definite reasons why they should not be.

As a digression in the effort to ascertain why the owner, whether corporate or municipal, should favor not only the approval of certain sub-contractors, but even urge the "designer" to obtain their co-operation when the plans are being prepared, a single example of each class, taken from actual occurrences, will be given:

A certain large corporation, an insurance company, was erecting a building of enormous size. The structural steel design was a difficult problem, but one well within the "designer's" power. Nevertheless, the president of the company insisted that a certain structural iron contractor should have his engineers check the design. The general contract was awarded, and the list of "subs" was presented to the "designer" for approval. On this list were two structural iron firms, one an independent firm, the other the direct agent of "the trust." The general contractor had noted that the "independent" bid was the lower. The president of the insurance company sent for the "designer," and made him admit that each firm could do the work equally well. Also, it was obvious that, since the general contract was let for a lump sum, the relative cost of the ironwork bids did not enter into the discussion. The designer was directed to approve the iron firm which made the higher estimate, because that firm, "having an intimate knowledge of the plans, showed from its figures that the work could not be done honestly for the price quoted by the independent firm." The "designer" gave his approval, as directed. Of course, the trust behind the higher bidder was financially affiliated with the insurance company, and it is interesting to note that the net cost to the successful firm executing the ironwork was quite a little lower than the bid of the independent. In that case, the general contractor simply paid a rebate unwillingly to the owner, but the "designer" was made the tool of an unfair transaction.

An example of the second class, having to do with municipal ownership, may be cited with equal ease. In many cities, appropriations for public buildings, bridges, and the like, are requested by the superintendent or commissioner having jurisdiction over the department which requires them. Assume that the request is passed upon favorably by a superior board, and goes to a body, such as a Board of Aldermen, for final ratification. This final deciding power, say, has not the right to alter the amount of the appropriation, or the purpose for which it is requested, but it has the privilege of withholding its approval as long as it wishes. If such approval is unreasonably delayed, it may be assumed that the superintendent or commissioner, anxious to gain credit for his administration by carrying out the much-needed work, if for no other reason, seeks to ascertain the cause of delay. He knows a man, who, holding no official position, nevertheless is cognizant of everything in this line. This man suggests that, if the appropriation can be passed, a certain "designer," whom he names, should be appointed. The superintendent or commissioner readily agrees. The "designer" knows nothing of all this, nor is he expected to. His first information comes from the man of no official position, who tells him he has been suggested as "designer" of this great public work.

Now as all governing bodies, whether Boards of Aldermen or not, have a guiding spirit, it may be assumed that the unofficial man obtains the ear of the guiding spirit. The appropriation is quickly passed, and the superintendent or commissioner, free and untrammeled, appoints the "designer" to prepare the plans. The course of events thenceforth is the same as that previously described, and, when the list of sub-contractors comes in, after the general contract has been let to the lowest bidder, the man of no official position is on the spot. Not being connected with the municipality, there is no legal reason why he should not be a stockholder, or on the pay-roll, of some of these sub-contractors who appear on the list. The "designer" not only knows that he owes his appointment to this man, but he may also have a vague suspicion that the work would never have been proceeded with, but for his efforts. What could be more natural, than that, confronted with the names of two sub-contractors of equally good standing, the designer should give his approval to the one suggested by his influential friend?

Should the "designer" feel reluctant about acquiescing in this matter, though after all it does not benefit him directly in a financial sense, he adopts the following expedient. He gives his approval to two sub-contractors, one of which is the favored firm. The general contractor thereupon beats each down to the bottom price, and then takes steps to find out which is the favored firm by the powers above the "designer." This one he takes care to employ, irrespective of the cost; neither does he fail to emphasize the fact, for it is "bread upon the waters." Discrimination cannot, it is true, be shown in the award of the general contract for municipal structures, but the right to reject all bids is always reserved. By this means, the unpopular or unpolitic general contractor can always be frozen out when his bid happens to be the lowest for the entire work, and he wishes to remain popular, even if it costs a few extra dollars in sub-contracts.

Up to this point, all that has been said shows clearly, or else the purpose of this paper has failed, that the situation of the "designer" is not of his own creation, being forced on him by circumstances, and that he does not profit directly to the extent of a dollar thereby. Also, it should be distinctly remembered, he has done nothing necessarily prejudicial to the safety or efficient construction of the work he has designed.

Somebody, however, must be making an undue or unfair profit. Why do the sub-contractors, and their financial backers, or their silent partner, "the man who holds no official position," do so many kind acts for apparently nothing, or at least for the ordinary contractor's profit only?

It is, of course, reasonable to infer that prior familiarity with the plans of the proposed work gives these sub-contractors a certain advantage in making up their estimates. Having had plenty of time to prepare an accurate statement of cost, they can naturally give a closer figure than their competitors who have, perhaps, had only a few hours to examine the plans and specifications on file in the office of the general contractor; but this advantage is not by any means the only one.

In the description of the preparation of plans and specifications, particular mention was made of the fact that nothing superfluous in design or requirements of construction is ever stricken out. When the opportunity offers, or when the subject happens to be one on which

the "designer" is not even fairly well informed, the sub-contractor, in his advisory capacity, can easily insert needless requirements into drawings and specifications. Should that subject be, for example, heating or plumbing systems, extra lines of piping may be shown, which only an expert in this specialty could with certainty declare needless; or, in the case of the specifications, many requirements as to elaborate testing, or extensive submission of expensive samples, may be inserted, the enforcement of which requirements may or may not be considered essential, depending on who obtains the contract eventually.

Let it now be assumed that the general contract has been awarded, that the sub-contractors, among whom are the favored ones, have been approved, and that the work has been started. Sooner or later the "designer" is informed that certain changes may be made in the plans, or certain requirements of the specifications waived, without detriment to the work. The "designer," being still conscientious, investigates these statements, even calls in other contractors for their advice, and finds that the requests to omit certain things are entirely reasonable. As to the elaborate requirements for testing, samples, and the like, they too are unnecessary, if responsible parties are doing the work. Who could be considered more responsible than those who assisted in its design? The request for their omission or curtailment is granted more or less readily.

At this point it may be remarked that there are two kinds of specifications, the loosely-worded, "blanket" kind, and the one filled with elaborate and detailed requirements as to tests, samples, and so on, both of which offer every opportunity for this kind of discrimination. The first class, the loosely-worded one, clear only on the one point that all power is vested in the "designer," can be interpreted so that the cost of the entire work, or any part thereof, may turn out to be anywhere from one-half the estimated amount to twice that figure. As for the other class of specifications, an impartial examination of the multiplicity of petty, often unnecessary, though always costly, requirements, will show that if enforced down to the last detail, the work could not be performed for twice the contract price. That all will not be enforced is, of course, discounted in the contractor's bid; but only the sub-contractor who is on intimate terms with the "designer," and who has assisted in preparing the lay-out, can be

reasonably sure of the omission of these petty and harassing stipulations, as far as his particular work is concerned.

Specifications of this latter class are notoriously frequent. Although they assist his scheme materially, it is not the politic sub-contractor who is responsible for them. They are the result of overweening vanity on the part of the "designer," who desires to insert therein every requisite and every obligatory condition that he has ever read of or heard about, and whose method of making each specification better and more complete than the last is to keep adding voluminous requirements, without ever weeding out the useless and obsolete clauses evolved during the earlier years of his practice.

Returning now to these requests for omissions. It has been assumed that the "designer" is an honest man. He may, and often does, demand an allowance from the sub-contractor when the request entails, not only less rigid enforcement of the technical clauses of his specifications, but the actual omission of material and work as well. Then the sub-contractor goes to the general contractor and lays the case before him. The latter knows the "pull" possessed by the sub-contractor with the owner, and is glad to assist. The two go over the plans and specifications together in minute detail. Now, it is rare indeed that, in the case of a large piece of construction work, something essential, either in design or specifications has not been inadvertently omitted by the "designer." In the writer's opinion, there has never yet been executed a large contract where there was not something installed, or some work done, which the general contractor could not have legally evaded on the ground that it was not shown or required.

It is to provide against these errors of omission, so certain to occur, that some designers have adopted the "blanket" clause. This is frequently found in the following form:

"Should any items be omitted in the drawings and mentioned in the specifications, or shown on the drawings and not mentioned in the specifications, or neither shown nor mentioned in either the drawings or specifications, but reasonably to be implied, and, in the opinion of the 'designer,' necessary to the complete and satisfactory execution or operation of the work or works, it shall be understood as expressed in both, and shall be carried out as if so expressed, and as directed by the 'designer,' to correspond in all respects with the remainder of the work and works."

Now, it is indeed fortunate for the general contractor that the courts do not interpret such a clause as conveying to the "designer" the all-supreme powers that it appears to. Nevertheless, it furnishes a basis for tedious litigation, on which the contractor desires to spend neither his time nor his money. The result is usually a compromise.

Having located the items "neither shown nor mentioned," the general contractor goes to the "designer" and makes a counter demand for extra payment. The "designer" is then in a quandary. He knows that if he endeavors to enforce his "blanket" clause, and if the amount involved is sufficiently large, the contractor will fight it. This involves legal expenses and delay in the execution of the work, either of which causes would bring down the wrath of the owners upon the head of the "designer." Neither is he willing, in most cases, to give in entirely, admit his error, and transmit to the owner, with his approval, the contractor's request for an extra payment. To do so would not only render him subject to the accusation of incompetency, and of having prepared an incomplete design, but also, especially in the case of public work, it might be impossible to obtain an additional appropriation.

Thus the "designer" also, is ready for compromise. This is offered by the general contractor, who agrees to do the necessary extra work without charge, if the "designer" will agree to the omission, without allowance therefor, of the unnecessary details, as requested by the particular sub-contractor heretofore mentioned. Here, again, the "designer," if particularly desiring to be honest to the end, may require a statement showing that the value of the work added is equal to that of work omitted. Of course, this is rarely the case, but the statement is always so rendered. The contractor is a better authority than the "designer," on the detailed cost of fractional parts of his work, and the "designer" can do nothing but accept his word for the accuracy of the statement.

This completes the chain. The industrious sub-contractors have not only secured their contracts against all competitors, by knowing how to bid a little lower, but they are actually making a considerably larger percentage of profit than their competitors would have made, even at the higher prices.

There is nothing actually illegal in all this, and engineers and architects of the highest ethical standards are constantly being forced

into just such situations. The resultant tendency toward discrimination and the unfair application of specifications cannot help but lower the standards of professional integrity. Graft and dishonest practice are only the next step downward. Such words lose their justly repelling force when the actions which they symbolize become our next-door neighbors. The taint of this corruption is spreading, not only among engineers and architects who are in the position of the "designer," but its baleful influence must of necessity cast its spell over the young engineers employed by many contracting firms, who are thus brought into contact with "the system," and who find their splendid ideals of the old-time engineering standards trailing in the wake of conscienceless competition.

Even though the writer may have succeeded in showing clearly the existence of this unfortunate condition of affairs and its importance to the Engineering Profession, the purpose of this paper would be but half accomplished were there not a possible remedy to be suggested.

When paid on a commission or lump-sum basis, the "designer's" fee is not always sufficient to insure a reasonable profit, over and above his office and running expenses, commensurate with the long years of technical training and experience in subordinate capacities considered so necessary as preparation, before he is entrusted with important work. Bearing in mind those unfruitful years, from a financial point of view, it has become customary for the "designer" to reduce his expenses, and to the same degree increase his profits, by inserting in the contract a clause requiring the contractor to pay the salary of the inspector or inspectors, employed by the "designer," in immediate supervision of the actual construction. These inspectors, however, are directly responsible to the "designer," and are subject only to his authority.

The first step, therefore, is to insure, by agreement between the owner and the "designer," that the fee or charge for professional services shall be properly commensurate, not only with the gross cost of the proposed construction, but also with the difficulties involved.

Secondly, it should be arranged that this charge should be paid in successive installments, in such proportion that four-fifths, and not one-half, of the total amount, should be paid upon completion of working drawings and specifications. This, for reasons heretofore noted,

corresponds more closely to the expenses of the "designer" up to this point in the work.

Thirdly, there should be a prior agreement between client and "designer" as to what specialists—such as heating, electrical, or sanitary engineers—are to be employed (if their employment is necessary), and what fees are to be paid to each. Their fees may come out of the "designer's" own charges, if need be, but the amount should always be predetermined in his agreement with the owner.

Next in importance comes the question of payment of the field inspectors during construction. It has been seen that this has been required of the contractor, who, of course, figures on the cost thereof in his estimate for the work. Hence the owner pays for it just as surely as though he signed the weekly salary check himself.

It is the writer's opinion that, in the case of men not so honest as the "designer" has been assumed to be, this system is a very fertile field for graft. The "designer" having the absolute right to appoint the inspector and fix his salary, from nothing at all up to the amount specified in the contract, may, by striking a medium between these two figures, save a considerable sum to the general contractor. This saving, or rebate, which really comes out of the owner's pocket, may be applied to various purposes, such as offsetting the contractor's claims for extras due to mistakes or omissions in the design, or to the more frankly grafting one of thereby obtaining the favor of a contractor influential enough to throw more work in the "designer's" way.

All this temptation could be eliminated by having the inspector paid directly by the owner, instead of indirectly, as at present. The salary could be fixed by the prior agreement between owner and "designer," and the selection of the individual could be made subject to the approval of both.

The inspector should also be subject to discharge by either owner or "designer," and his duties should consist in rendering daily reports, in duplicate, to both, showing first, the exact progress of the work to date, and secondly, describing in detail any and all variations from the requirements of plans and specifications. This inspector should not be given power to condemn work. His reports, coming daily under the eyes of the engineer inspectors in the regular employ of the "designer," would enable them to perform judicially all the condemnation necessary by letter, or an occasional visit to the work. The field

inspector, however, being constantly on the job, may with propriety warn the contractor when incorrect or improper work is being done, and announce his intention of reporting the same. The contractor must then decide whether or not to persist in the face of such warning.

Then it is essential that all allowances for work omitted, and all extras for additional work done, should be settled by one of the two following methods: First, as far as possible, the deduction or the extra should be computed on the basis of "unit prices," to be named by the contractor in his bid. Second, when the first is not possible, such amounts should be decided by arbitration between the "designer," the general contractor, and a third party acceptable to both. The valuation should be based on actual cost sheets of the work involved, to which should be added, or from which should be subtracted, a certain fixed percentage representing the contractor's profit. This percentage should be fixed, and be a component part of the contract when it is signed. No extra work should be accepted gratis from the contractor. If such did occur, it would immediately come to the owner's attention through the duplicate reports of the field inspector, and should indicate to him that some kind of reciprocal favoritism was in progress between contractor and "designer."

By the adoption of these safeguards, it would seem that, not only intentional dishonest graft could be prevented, but also the more subtle kind with which the "designer," though profiting nothing directly thereby, is continually being entangled. The remedy here pointed out is not intended to produce a check on the ambition of the "designer," nor does it imply presumptive suspicion of his honesty. On the contrary, it is a true safeguard against a combination of circumstances which would place him in a position, to say the least, unenviable.

There is a secondary advantage to the Profession as a whole, namely, that under the protection here outlined, the work of the "designer" may be judged on its own merits. No longer may it be inferred that the mistakes and omissions of the young "designer" are necessarily the natural result of his inexperience. No longer will the apparent flawlessness of the work of the older "designer" be ascribed to his more mature knowledge, when he shall have become no more amenable to the wily subterfuges of the contractors' system, which, to its own advantage, conceals mistakes. The client or owner will obtain

the work for which he has paid. The "designer," without pull or political affiliations, will be on the same basis as the one whose finer sensibilities have become blunted through intimate relations with scheming contractors.

After all, when engineers have written and talked over the technical details of their work, have commented upon and discussed this or that theory of design or method of construction, does there not remain something even more important in the consideration of those high ideals which should underlie all else in the Profession? It is, of course, important that engineers should be true to their work, and to those standards of knowledge and efficiency set by those who have gone before, but is it not equally vital that they should be true to themselves?

## DISCUSSION.

Mr. Stern.

EUGENE W. STERN, M. AM. SOC. C. E.—The author has touched on a number of sore spots in the conditions often existing in building operations, in the relationship of the several parties to the work, and it might be well to analyze this situation briefly, in order to arrive at a proper understanding of the relationship between owner or client and professional adviser or designer, be he architect or engineer, and contractor.

Let it be assumed that an owner desires to construct a large building, involving in its design, in addition to the usual architectural problems, a number of engineering specialties, such as structural, mechanical, electrical, etc.

Let it also be assumed that the owner wants the building properly constructed, for the purpose intended, for the least amount of money, and as expeditiously as possible. The word, "properly," is used advisedly, for the owner who wants the cheapest kind of work, without regard to conditions, is beyond the pale of this discussion.

Let it also be assumed, as is usually the case, that the owner himself has not the requisite knowledge to design and supervise the execution of such a piece of work. Therefore he must employ some one to do this for him, that is, to make complete plans and specifications, receive bids, award contracts, supervise the execution of the work, and see that his client's interests are properly protected, in the entire transaction.

To accomplish this, he may employ:

(*1*).—An architect to handle all the work, including the engineering specialties, and be responsible for it all; or

(*2*).—An architect for the purely architectural work, and specialists (separately) for the various engineering problems, such as foundations, structural, heating and ventilating, electrical, etc.

The first method is to be preferred, for the reason that some one, with a general knowledge of all the different problems, must coordinate and harmonize them, so as to produce a whole which will accomplish what is required.

Thus the architect, not only becomes responsible for the general scheme and for the artistic treatment, but also acts as chairman, so to speak, of a board of engineering specialists, and, to obtain the best results, should himself have the power of selecting them. This is the usual method, and undoubtedly has produced the best results.

Now, the question arises: Who is to pay for these engineering specialists? For, in very few architectural offices are competent engineers employed as part of the regular organization, and in none, it is

Mr. Stern.

safe to say, is all the engineering talent regularly employed to handle properly the problems which may arise in modern building construction.

The American Institute of Architects has answered this question by embodying in its "Code of Professional Practice, and Schedule of Proper Minimum Charges" the following clause:

"Where heating, ventilating, mechanical, structural, electrical, and sanitary problems are of such a nature as to require the services of a specialist, the owner is to pay for such services."

If architects were all living up to this reasonable principle, the "precarious expedients" mentioned by the author would not be necessary. It is due to ignoring this principle, in the endeavor to obtain commissions from prospective clients by underbidding one another, that many architects thus reduce their charges, and agree to pay for the services of engineering specialists themselves, with results often prejudicial to the owner's interests.

Of course, the conscientious architect, even if his compensation be not sufficient, will see to it that the client's interests are properly safeguarded, by himself employing competent specialists; but, in far too many cases, this is not done, and the client's interests suffer, for either the specialist's work is indifferently done in the architect's office, or he employs cheap so-called specialists, or calls on the contractor to loan him the services of his engineer, often for no compensation, or at best a small one, to be paid only if this contractor does not secure the contract for his part of the work.

Obviously, this latter method is quite economical to the architect, and also satisfactory to the favored contractor; but why do the client's interests often suffer in this case? For these reasons: The contractor's engineer may be thoroughly competent, and may design the work in a first-class and conscientious manner, but the knowledge of the fact that a competitor has designed the work for the architect always leaks out, somehow or other, among the other bidders, and is, of course, a sure indication to them that this competitor, thus favored, has a preference in the architect's office.

Such a condition leads naturally to the bidders very often "conceding" the work to the favored contractor, after having "pooled" their interests, and thus the owner pays far more for the work than he should.

Even if conspiracy to raise the price has not occurred among the bidders, the favored contractor having been awarded the contract, suppose questions arise later which need adjustment, can the client (having no expert adviser of his own) expect unbiased professional advice from the other party to the contract—from the one who is looking for profits? Is it reasonable to suppose that his interests will be properly

Mr. Stern. safeguarded by such a one? Will the contractor's engineer be inclined to lean toward the owner's or his own employer's interests? The answer is obvious.

The substance of the foregoing is, that it should be recognized as an axiom that an architect is doing his client's interests grave injustice when he allows himself to be under any obligations to the contractor; and, furthermore, that he is placing the contractor's engineer in a false and difficult position when he asks him to serve two masters. The speaker knows of many cases where just such things as have been stated have happened, but it would be violating professional confidence to mention them by name. Doubtless many others of the profession have had similar experiences.

Mr. Crosby. W. W. Crosby, M. Am. Soc. C. E. (by letter).—The writer has read Mr. Hawkesworth's paper with much interest and sympathy, and has been especially struck with the paragraph concerning the duties of an "Inspector." The author has "put his finger on the button" of a source of great conflict between contractors and owners, or referees. As a rule, contractors, or their working representatives, are older, and much more experienced in dealings with others, than the best of inspectors. When an inspector becomes the equal of working superintendents along these lines, he seldom remains an inspector long. If, therefore, an inspector, incapable by lack of experience and maturity of judgment, is given authority and placed in a position to bind or hamper the decisions of the referee named in the contract, the result may be unfortunate or disastrous. Unscrupulous contractors undoubtedly exist, who do not fail to take advantage of such a situation. The writer regrets that so many contractors seem to regard the obligations placed on them by their contracts as not mandatory and not matters to be lived up to in spirit because of the agreement that they shall be fully carried out. Many contractors, on the contrary, seem to regard the specifications under which they agree to do work as merely statements of the things which the owner or referee will try to accomplish; that it is the duty of the referee to enforce them if he can; and the privilege of the contractor to evade as many of them and as far as he wishes. To place a young, perhaps inexperienced, party in a position to decide the many points that may be raised by an experienced superintendent or foreman is almost sure to prevent the owner, who pays for work done according to the specifications, from getting what he pays for, to which he is entitled, and which the moral obligation on the contractor alone should compel the latter to deliver. The writer can recall numerous instances where, as the inspector's authority was not clearly limited in the contract, the contractor claimed that the referee and owner were estopped from finally securing the kind of work the owner was clearly entitled to and the contractor had agreed to give him, and had named his price

for giving him, because the inspector had "accepted" the inferior work or had failed to "condemn" it. Mr. Crosby.

The writer believes it is far fairer and better in every way, including all considerations of justice to the contractor and to other bidders, to provide, as suggested by the author, that an inspector shall simply report the facts, and that the decisions shall be left to the owner or the experienced referee specified. Some greater delay may occur in securing final decisions under the latter method, but the decisions will undoubtedly be more just on the average, and, except in those cases where questions are raised for the purpose of evasion or for making difficulty, when delay in the decision may be justified, they will be more in accord with the spirit of the contract. In the work of the writer, the following clauses are contained in the specifications:

"An Inspector employed by the Commission may be stationed on the work under the contract by the Chief Engineer to report whenever the Contractor appears to fail in carrying out the terms of the contract or specifications in any particular. Any advice which an Inspector may give the Contractor shall in no wise be construed as binding the Chief Engineer in any way nor releasing the Contractor from the proper fulfillment of the terms of the contract as determined by the Chief Engineer. An Inspector shall perform such other duties as the Engineer may indicate. The Inspector shall in no case act as a foreman for the Contractor nor interfere with the management of the work by the latter.

"The amount of work done by the Contractor shall be measured by the Engineer. In that character of work which would require for its measurement a detailed tally of the materials as delivered on the work, a tally shall be kept by the Inspector who shall at the end of each day compare his tally with that of the Contractor or foreman in charge. The Inspector shall send daily his tally, with the Contractor's or his foreman's signature, to the Engineer. Should there be a dispute between the Inspector and the Contractor as to the amounts in any particular instance, the Contractor must immediately send his account to the Engineer. If no tally of materials delivered, other than that of the Inspector, is received by the Engineer within five days after the receipt of the Inspector's tally, the Engineer's estimate may be based upon the reports as made by the Inspector, whether or not these reports are signed by the Contractor or his foreman, and they may be the basis of payment to the Contractor. Whenever any differences exist, the decision of the Engineer shall be final and binding upon both of the parties to the contract."

Complaints of delay on account of the lack of authority of the inspector, especially where the latter has been young or inexperienced, have been received from contractors who, it was evident to the chief engineer from the general conduct of their work and personal attitude, were ignorant, incompetent, or at least not trying fully to live up to their moral obligations; but serious complaints from efficient and conscientious contractors have not reached the writer. On the

Mr. Crosby. contrary, the methods of his office seem to be approved by those whose approval is valuable.

Mr. Branne. J. S. BRANNE, ASSOC. M. AM. SOC. C. E. (by letter).—This paper is a plea for the maintenance of a high professional standard among engineers, not only as to the product turned out, but also as to the manner in which the materials are collected for a design of some magnitude and having a variety of detail in several distinct branches of engineering, a thorough knowledge of all the subjects to be considered being rarely available in any one office. The ends desired by all engineers are: To carry out work in such a way that the result is excellent, not only because it is economical and safe and gives a good return for the money invested by the owner, but also because the means used at all times to achieve such ends are just to all concerned, both in planning and building the work, by having clear drawings, specifications which are concise and without redundancy, an equal opportunity for all bidders, and favoritism to none. This paper, which calls attention to abuses, more or less apparent, and suggests means for opposing them, is very timely, and will benefit the Profession, and therefore the measures it advocates should be supported.

There is hardly a piece of work the perfect execution of which does not involve many specialties, from two or three to perhaps a dozen. This is necessarily so, as the tremendous strides with which the engineering arts and sciences have advanced during the last 25 years have enabled business men to place on the market an almost endless variety of appliances and materials, all produced by special knowledge and careful study of economy and utility. What man, then, after attending to his own special work, that is, work in which he is pre-eminently trained, say as a sanitary, electrical, hydraulic, structural, or railroad engineer, not to mention all the other specialties, and, as a rule, finding that it takes all his time to keep abreast with the developments in his own line, can also pass on all the specialties in other lines, admitting that he has good judgment and is a hard worker? Clearly, he can not, but must call to his assistance men who are specially trained in other lines which they have made their life study. The difficulty then becomes apparent: He has not enough money allotted to pay for all this special knowledge, and, unless he has plenty of time to study the matter up himself, he has to accept free advice from the men who sell these various articles. Free advice, however, is not free to the owner, as the laws of compensation hold good here as elsewhere, and while there can be no proper objection because the owner pays for the advice, yet it has the disadvantage that it stifles fair competition by giving the favored free adviser special privileges in a thorough knowledge of the plans or by introducing special articles, of which there may be several varieties, but his own is specified. Clearly, it is to the interest of the owner to pay a specialist for his unbiased advice; for the owner

must pay for advice, and why not pay a man whose sole object is the safety and economy of the work on which he is consulted, and who has no special device of his own to sell? Mr. Branne.

The engineer's object is to carry out works for the welfare and convenience of man in a safe and economical way; in other words, the engineer makes improvements possible by his knowledge of the applied sciences, and it is his sole duty to plan his special work in such a way that attention is paid to locality, permanence of work, future requirements, present resources, and other matters. The "designer"—as Mr. Hawkesworth terms the engineer or architect-in-chief—will then give a fair chance to all bidders, by having the features with which he is acquainted only in a general way planned by an engineer specialist; for the specialist, without confining himself to one or two things, can indicate clearly to all bidders what is wanted, and being a judge of the excellencies of all, he gives the freest scope to fair competition. It is granted that the manufacturers and general contractors have just as able engineers at their service; but, at the same time, the manufacturers are bound to look after their own "future requirements, resources, etc."

Mr. Hawkesworth has suggested many ways by which the interests of the Profession may be safeguarded and mistakes in the conduct of business avoided, thus making for the maintenance of high standards. Little can be added in regard to the methods advocated, but it seems pertinent to say that, to carry on work along such lines, giving the best in everything, can be possible only when owners understand the benefits accruing to them by paying enough for professional services so that skill can be employed. It appears, therefore, to be the duty of all engineers to try and get work, not simply by stating how cheaply their services can be had, but by showing how cheaply work can be carried out when they are paid well enough to give attention to all details; this would be a sort of campaign of education, bound to be beneficial both to engineers and owners.

An engineer who has the good fortune to carry out his work on the highest professional lines will gain still more good fortune as the years roll by, if he manages to be alive when his well-earned reputation becomes firmly established, as it is bound to become, sooner or later; for painstaking care in all details, however small, will enlarge his knowledge and ripen his judgment, and, although no man can plan work so as to be free from mishaps of some kind or other, it is his duty to take all precautions. Probably the best way for engineers to get in line for a high class of work is to learn all they possibly can about their specialty, and enough about other lines to pick out the men who can assist them most efficiently, and let them do their end of the work. Even if engineers are, financially, immediate losers, due to insufficient funds, the results of such co-operation must produce the

Mr. Branne. best returns, and will eventually gain for an engineer the reputation of being reliable and a man who takes enough pride in his work to allow no part of it to be ill performed.

Mr. Allen. ANDREWS ALLEN, M. AM. SOC. C. E. (by letter).—The thanks of the Engineering Profession are certainly due Mr. Hawkesworth for his timely paper. There is far too little attention paid to the ethical and moral standards of the Profession in papers and discussions published by the Society, as they usually deal with physical facts and methods of work, things done and the mechanical tools for doing them, forgetting the human elements which are the most important of all.

The engineer, in the different lines in which he works, sustains important relations, and is vested with great responsibilities which involve far more than technical skill. As engineer in charge, or as "designer," he represents the business interest of the owner, and at the same time is given supreme power as arbitrator between the owner and the contractor. As contractor, or as engineer for the contractor, he has to conduct difficult negotiations with the owner or his engineer, see that the work is done right and in accordance with the requirements, and get a profit out of the job. Each engineer, and, to a smaller extent, each subordinate, has an organization to maintain, the efficiency of which depends largely on the loyalty, confidence, and cooperation he is able to secure among his men. Success depends more on the personality, vigor, fairness, and honesty of the engineer than anything else, and still technical societies are doing almost nothing to direct or encourage growth along these lines; and engineering business methods are doing quite the reverse. If an engineer does not happen to be born with these qualities fully developed, he has a hard time getting any assistance in developing them. Nearly all educational methods are based on the idea that good morals cannot be taught in schools, and the young man is expected to get this part of his education at church, where he is very apt to get only the husks of ethics or morality, with no ideas as to applying them, or in the home, where the faults of the present generation are perpetuated. The natural result is that most young men get no moral education at all, and are thrown into business conditions which they do not fully understand, and with no real conception of right and wrong. If things look a little queer to them, they just excuse them under the old motto that "Business is business," which, if it means anything, means that any methods are right which bring money into your pocket or the pocket of your employer. If men are not hopelessly corrupted at the start, they drift around without any adequate moral standards—unless they are so fortunate as to get their moorings somewhere—and build a system of ethics which satisfies their requirements. It is no wonder, therefore, that many of them go wrong professionally, not engag-

ing in acts which are criminal under the law, but acts, such as those mentioned by the author, which simply show the lack of a proper ethical standard or the strength to live by it. Mr. Allen.

The author has mentioned only a few of the things which are being done every day, both by "designers" and contractors. A "designer" or an owner will often get a detailed plan of some part of the work from a contractor, cut off the name, and submit it to other contractors for bids. A contractor will frequently make use of his opportunities, when called into consultation by the "designer," to "load up" the work so that he is able to underbid all competitors, and then, as the author states, cleverly "unload" again by offsetting one change against another, make a good profit, and perhaps do a most excellent piece of work where another contractor might have lost money.

These are rather flagrant but none the less common examples. Going a step farther: How many engineers, and how many contractors, do their work as though it were their own and they were doing it for themselves? How often one hears the question: "Who pays for this? Is it lump sum or unit price? If we have to pay for it, we'll leave it out; if the other fellow pays for it, we'll put it in." How many times does the "designer" refuse to allow or to make a desirable change in his plans for fear the contractor will make a little more money. How often does the contractor fail to call attention to changes or modifications in methods or plans, which might benefit the owner or the work, because his own interest might suffer thereby. So it is all the way down the line, until one cannot help wondering what is really the matter. The author suggests certain remedies, many of which are excellent and all of which show the right spirit, but here one runs up against an economic law. The owner is paying the bills and does not see why he should pay for so many kinds of expert advice when so much of the best expert talent is already in the service of the contractors or manufacturers, and necessarily so, because their very life as manufacturers or contractors depends on such talent. A great deal of special consultation usually means a duplication of effort and expense, and an economic loss. If the consulting specialist should ever take full control of all departments of designing, the writer believes that there would be a swift deterioration in productive efficiency and ultimately in engineering merit. The place for the expert specialist is near his tools.

The writer is afraid, therefore, that the author's actual remedies are directed more toward the symptoms than the real disease. But what is the real disease? Partly commercialism, the wish to get something for nothing, but principally, as it seems to the writer, the fact that the immediate interests of all the various parties to con-

Mr. Allen.

tract work—owner, "designer," contractor, and sub-contractor—are necessarily and absolutely at variance.

The immediate self-interest of the owner, before the work is let, is to obtain the lowest possible prices by every means in his power, and after the work is let, to get as much as he can out of the contractor. The immediate self-interest of the "designer" is frequently to make the work cost as much as possible, and to slight it all he can. The immediate self-interest of the contractor before the work is let, is to underbid his competitors, and after the award, to get out as best he can. It is a state of war in which each party has many weapons, and neither can be blamed very much for using them. It is not much worse for the contractors to pool a job than for the owner or "designer" to play one bidder against another. Both are stratagems of war, and the only marvel is that things are no worse. An honest contractor and a fair and broad-minded engineer are both entitled to the very highest credit, for they can only be developed, under the present system, by forgetting immediate self-interest and looking forward to the ultimate reward of true honesty.

So we start with no adequate moral training, practically nothing is done in the professional societies, and engineering business methods are such as to put a premium on self-seeking cleverness, and not on honesty and real manhood.

The writer realizes that business conditions are matters of gradual development. Engineers could not change their methods suddenly if they would, or if they saw clearly the way to change them, but they can take a step once in a while in the direction of better conditions, and so gradually improve them. It is the writer's conviction that conditions never can be good until the interests of all parties connected with engineering work, from owner and "designer" to contractor, are all directed to the same end, and that end, the excellence and true economy of the work. The thing that blocks the path of improvement is the method of contracting for engineering work by price competition.

Anyone familiar with contract work knows that a tremendous price is paid, in shoddy work, inefficiency, and moral diseases, for competition, and yet we are told that it is a sacred thing, and that absolute freedom of competition is necessary to progress. The writer freely confesses that he is a heretic. In the first place there never has been, and never will be, free and perfect competition. In the second place, it has already become necessary to substitute "regulation" for competition among the railroads, and it soon will be necessary to do the same thing with the trusts. It is perfectly true that, in the past, much progress has come through competition. In the same way, much progress has come through savage warfare, but it does not follow that price competition is necessary or beneficial to-

day any more than it follows that we should throw away our government regulations, arbitrations, and courts of law, and go back to settling our disputes with our fists or our battle-axes. Mr. Allen.

Of course, something will have to take its place. Most men still need a great incentive to put forth their best efforts; but why not devise some method of securing a "competition of excellence," instead of price? And such a method can be devised. The "fee basis," modified perhaps so that profits below or losses above the estimated cost are shared in certain proportions, seems to offer a hint of the true method. The contractor is assured of a reasonable profit, and is also benefited by economy of operation. The interests of all parties are as near to those of the owner as it is possible to make them. The owner gets the benefit of the contractor's experience and equipment. The contractor has to depend on his reputation for honesty and efficient work, instead of a low bid, for getting his contracts, and, still more important, all parties can co-operate, after the contract is let, to obtain the best results for the benefit of all. Anyone who has done work fairly and honestly under this method will bear testimony to the way in which the difficulties, misunderstandings, and "dangerous expedients" vanish like mist before the sun. The expert or engineer of the contractor has a recognized standing at court. The "designer" is free to devote himself to the larger elements and relations of the work, and to avail himself of the full value of the expert services of the contractor or manufacturer, and the contractors will be selected because they are the best in their lines, and not because one happens to leave out enough in his estimate to make him a low bidder.

Of course, this is Utopian. It will require great changes in business methods, and the cutting away of much dead timber. It will require higher moral standards, but it will breed them in turn, and the writer will be satisfied if he has succeeded only in calling attention to the problem, in the hope that our thoughts and efforts may help future generations to outgrow some of our present trouble, and build wisely and well, not only their engineering and architectural works, but the character and manhood of the profession and of the race.

GUY B. WAITE, M. AM. SOC. C. E. (by letter).—On first glancing at this paper the writer thought that it was one more of the numerous censures for the contractor and praise for the zealous efforts of the designer to remedy the evils existing in the business of the designer, owner, and contractor, but a careful reading has satisfied him that there is one designer who is able to give an unbiased opinion of the conditions existing, in his particular sphere, between designer, owner, and contractor. Mr. Waite.

The author is undoubtedly revealing truths derived from personal

Mr. Waite.

experience. Evidently, he does not belong to that class of designers who assign all the evils existing in the contracting business to the contractor, and give all the credit for efforts to remedy the same to the engineer.

Although the author has covered the particular field of action which he has in mind with credit and satisfaction to both his profession and the contractor, yet the writer feels that it is not entirely out of place to refer to other actions between designers, owners, and contractors, not mentioned in the paper. He refers more particularly to actions between designers and contractors which, ethically, he would term "dishonest honesty."

Competent designers know that all valuable experiences, as to the costs of any new design, etc., are luxuries which are expensive in time and money. If such designers are wise, they save the necessary time and money for these experiences by taking into their confidence some honest and competent contractor. Seldom does the contractor hesitate to drop all and give his best advice to the designer, even when his running expenses are such that time is money to him.

There are many contractors giving such advice, who, in no way, would mislead a designer for any personal interests, and would not wish to place any designer in a position to feel that he was under obligations. All that such a contractor would expect would be an equal chance, on the same plane as other contractors, when the time came to take estimates and award contracts. The interchange of knowledge between the honest designer and the honest contractor would seem to warrant a mutual condition of confidence, whereby the contractor deserves the same consideration as given to other parties who have not assisted so freely in making the engineer's or the architect's plans practical. However, a peculiar condition sometimes exists among designers and contractors, whereby, after the contractor, at the suggestion of the designer, has done all that was possible, the latter seems to think it his professional duty either to forget him entirely or place him at a disadvantage. The feeling on the part of the designer seems to be that some one may suspect him of being too friendly with the contractor. If such a contractor should be so unfortunate as to beat all comers, however much they forgot to include, and obtain the contract, then the appreciating designer becomes worried, and studies how he can prove to the owner that he is working solely for him.

The designer at every turn stands on the blanket clauses in his contract, which state that "everything necessary, whether shown or specified, shall be furnished without extra cost." This is intended to cover his many oversights.

When there is any doubt as to the plans and specifications covering extra work, and the owner is convinced that he should be indebted to the contractor, then the designer intervenes, and advises the owner that

he can just as well have it for nothing. If one kind of cement or one form of patented device will serve as well as another, and the contractor is being held up for a large bonus, the designer asserts his authority, and demands that there shall be no variation. He shows the owner from time to time how it pays him to have an "honest designer," and how much he has obtained from the contractor for nothing. It never occurs to him that the cost of the next work he designs will be increased by every one who knows him. Mr. Waite.

Another designer, whose character differs slightly from that of the foregoing, is the one who feels himself to be so weak that he imagines it will make him appear strong to persecute his best friends and grant favors to his enemies. In this way he seems to think he can establish the fact that he is very fair.

Characters of these types are quite common among "highly educated" professional designers and those who want people to think they are highly educated. The writer mentions these classes, and places them in the list of "dishonest honest" designers, not from personal impressions, but because they seem to stand in their own light, and should be considered when making up a code of ethics between the designer, the owner, and the contractor.

J. H. GANDOLFO, ASSOC. M. AM. SOC. C. E. (by letter).—It has often been said of engineers that they are so interested in the technicalities of their profession, and so absorbed by the requirements of the immediate work in hand, that they have neither the time nor the inclination to consider the broader ideas of life, or those general questions that link the Profession to the rest of mankind. This fact is typically exemplified in the opening paragraph of this paper, wherein the author thinks it necessary practically to apologize for presenting a non-technical paper. The Society should welcome such contributions to its literature, and it would be to the advantage of the Profession, and would broaden the understanding between it and the general public, if more papers of this class were presented. Mr. Gandolfo.

Mr. Hawkesworth has done well to call attention to certain questionable practices by some engineers. Of course, there is a natural tendency to keep "mum" on such a subject, but the time has come when it is the duty, not only of the engineer, but of everyone, to expose "graft" in any form or shape. Unfortunately, we are living in an age when, if a man rides on a transferred transfer ticket, he is treated as a criminal. On the other hand, if a man issues to the public so-called "securities" that represent nothing, and, further, makes way with the entire funds of banks by borrowing on such "securities," he is applauded as a financier. Perhaps the majority of people do not realize to what an extent "graft" (which is only another word for "dishonesty") has developed in some classes of engineering enterprises, and the following occurrences, which have been brought to the writer's

Mr. Gandolfo.

attention, may be of interest. In this discussion the term, "designer," will be used in the same sense as in the paper.

On a certain job involving the use of some 4 800 tons of structural steel, the contract was let to a steel contractor without calling for bids and with the understanding that the contractor was to prepare the general and detailed plans, which work was to be supervised, and the drawings finally checked and approved, by the "designer." The reason for this method of procedure developed later, when it was found that several directors of the purchaser's company were also on the board of the steel contractor. The "designer's" chief assistant engineer, a young man, warned him, before the contract was let, that, as it was to be on a pound-price basis, fraud was likely to creep in, as there might be an unnecessary increase in the weight of the structure. He was told by the "designer," a man much older and more experienced than himself, that such a concern as this contractor would not stoop to any such practices.

As the work progressed, the "designer's" assistant repeatedly had occasion to call the attention of his superior to places in the design where totally unnecessary material was being introduced. The "designer," influenced perhaps by the knowledge of the similarity in directorship, did not take any radical action, in spite of several stormy interviews with the contractor's engineers. The final result was that this steelwork cost, in round numbers, $50 000 more than it should.

Another incident, which concerns an architect, shows, by inference, what may be done. Three firms, one of which will be called the "favored contractor," were asked to bid on a certain job. When the bids first came in, that of the "favored contractor" was found to be the highest. All the bids were rejected, some minor alterations in the plans were made, and new bids were called for. Again the "favored contractor's" bid was the highest. The same process was repeated, and, on the third attempt, the bid of the "favored contractor" was just $50 less than that of the next lowest bidder. Of course, no one can say that there was collusion between the "designer" and the contractor, short of a direct confession from one or the other, but the facts as they are known are submitted for consideration.

One more illustration, concerning a general contractor: In this case, also, there were said to be some of the same directors on the boards of the purchaser and the contractor, and it was also said that the same banking house was financing both enterprises, but of this there is no proof. The contractor in question was brought to the attention of the "designer" after bids had been received and the contract was about to be closed. Needless to say, this contractor obtained the job, by what means is not known, so he will be given the benefit of the doubt, and it will be taken for granted that he was honestly the lowest bidder.

Mr. Gandolfo.

As the work progressed, it was found that inferior materials and inferior workmanship were being put into the job. The inspectors made report after report to this effect, the division engineer, who had charge of this work, stormed and protested, and the "designer's" assistant wrote report after report to his chief, setting forth in detail wherein the work was not up to the plans or specifications. In the meantime the contractor went calmly on the "even tenor of his way," secure in the knowledge that he held "the cold end of the poker"; and so it proved, for in spite of united action on the part of all the subordinate engineers connected with this work, nothing was ever done. And further, as the time drew near for the final settlement of this contract, every subordinate inspector or engineer, both on the purchaser's side and on the contractor's side, who had been on the job from the first, and who knew where details had been omitted and where credits were due, was dismissed on one pretext or another, so that when the work was finally finished, not one of the original engineers, except the "designer," was on the job. Shortly after, and before the final payment, even the "designer" thought it expedient to take an extended trip to Europe, leaving the matter of settlement in the hands of those totally ignorant of the details and progress of the work.

In closing, the writer may state that perhaps it has been his fate to have more of these matters brought to his attention than falls to the lot of most engineers, and he hopes that this is so. Tennyson has said:

"There lie two ways to every end,
A better and a worse."

The writer trusts that, as time goes on, it will be found that engineers have always, without exception, followed the first of these two roads.

Mr. Hawkesworth.

JOHN HAWKESWORTH, ASSOC. M. AM. SOC. C. E. (by letter).—In closing, the writer feels that little remains to be said, except to thank those who have contributed to the discussion for their commendatory interest. In their unanimity of opinion regarding the unfortunate state of affairs which the author sought to portray, it is perhaps regrettable that so little attention was paid to the direct method of relief suggested in the paper. On this latter point, it was felt that suggestion, or even adverse criticism, would have been of value.

It is true that, in private communications to the writer, not intended for publication, the paper was attacked, and it is to be regretted that these communications could not also have have been presented to the Society. The assertion most frequently made was that no large piece of work could be planned or executed without a certain amount of leeway, a sort of reciprocal attitude of "give and take" here and there, between "designer" and contractor, in order to eliminate errors of judgment and faults of design.

Mr. Hawkesworth.

The writer never intended to claim that competency on the part of the "designer" necessarily implies a perfect design. However, for fairness of comparison between the work of various "designers," it does indeed seem to be necessary that hidden errors should be brought to the attention of the one who is paying for the work, and that any departure from the requirements of a lump-sum contract should be adjusted by some other method than a private arrangement between "designer" and contractor.

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TRANSACTIONS

Paper No. 1145

# WATER SUPPLY FOR THE LOCK CANAL AT PANAMA.*

By Julio F. Sorzano, M. Am. Soc. C. E.

With Discussion by C. E. Grunsky, H. F. Hodges, Theodore Paschke, Allen Hazen, C. M. Saville, and Julio F. Sorzano.

On March 16th, 1909, the Chamber of Commerce of the State of New York appointed a special committee to

"* * * make a study, from the standpoint of the requirements of the world's shipping, of the problems involved in the construction of the Canal at Panama, and report what, in its opinion, should be done, engineering and financial considerations permitting, to make the Canal best subserve the needs, for all time to come, of a constantly expanding commerce."

The writer, as a member of that committee, has lately had the opportunity to study many of the very interesting problems brought before it.

Among these, perhaps the question of "water supply for the locks" is one of the most important, on account of the effect it may have on the ultimate capacity of the Canal, and on its ability to meet the future requirements of the service for which it is being built.

Originally, when the proposed locks were of considerably smaller dimensions and the requirements of navigation had, perhaps, not been estimated to their full magnitude, the available water at the Isthmus was considered sufficient for all the needs of the proposed waterway;

* Presented at the meeting of November 17th, 1909.

but now, with the greatly enlarged locks under construction and the increased sizes of the vessels afloat, it seems that this question could and ought to be studied again under these new conditions and with due regard to the ever increasing requirements of navigation.

It is under such impression that the writer ventures to submit to the American Society of Civil Engineers the following considerations, not with the object of criticizing the plans now in execution, but only with the earnest desire of starting among its members a discussion of a subject believed to be of great importance to the country.

To make this analysis clearer, it is well to establish here some of the elements that enter into the problem, viz.:

The main features of the lock-canal system;
The requirements of navigation;
The available supply of water; and
The consumption of water.

## Main Features of the Lock-Canal System.

It is well known that the adopted plans for the Lock Canal comprise a high-level waterway between Colon and Panama, consisting of:

*a.*—One sea-level section, on the Atlantic side, from Colon to Gatun, about 7 miles long.

*b.*—One set of twin, three-flight locks, at Gatun, with a total lift of 88 ft., connecting the sea-level section with the high-level lake at Gatun.

*c.*—An artificial lake to be formed at a level of 87 ft. above the sea, to be used for the storage of water for the locks. In this reservoir, to be named "Gatun Lake," will be dug a channel 45 ft. deep and 24 miles long, with submerged banks, for the navigation between the Gatun locks and the Culebra Cut. This reservoir will have an area of 170 sq. miles at high water and about 100 sq. miles at 60 ft. elevation. More than 90 islands will be formed by the flooding of that lake through the hills of the Canal Zone.

*d.*—The Culebra section, or high-level canal through the Culebra Cut, extending from Gamboa on the lake to the Pedro Miguel locks, about 7 miles, toward the Pacific side.

*e.*—One set of twin-locks at Pedro Miguel, with a lift of 32 ft. at high water.

*f.*—One section of intermediate canal, about 1½ miles long, between Pedro Miguel and Miraflores, at Elevation + 55 ft.

*g.*—A set of twin two-flight locks at Miraflores on the Pacific slope, with a maximum lift of 66 ft.

*h.*—A sea-level section from Miraflores to deep water on the Pacific, near Panama; about 8½ miles long.

The total length of the Canal is nearly 50 miles, of which about 15½ miles are a sea-level canal at tide water, and about 31 miles are at an elevation of 87 ft. above the sea. The remainder is in locks and the intermediate section.

This waterway will have 23 changes of direction, and is to be navigated by a "polygonal route," so as to avoid the various islands and shoals which will be formed in the lake by the existing hills and by the high grounds on each side of the route.

The twelve locks are to be operated with the water accumulated and stored in that artificial lake, from the annual discharge of all the streams emptying into it; that discharge and rainfall being the only sources of water supply for the whole system.

It is expected that the depth of water in the lake, under these plans, will vary only from 47 ft. at high water to 40 ft. at low water, at the end of the dry season.

The purpose of this monograph is to ascertain whether this 40-ft. draft can be maintained at all times in the Canal under the conditions which are possible and probable in that locality.

## Requirements of Navigation.

*Draft.*—The law authorizing the construction of the Canal at Panama, stipulates that:

"Such canal shall be of sufficient capacity and depth as shall afford convenient passage for vessels of the largest tonnage and greatest draft now in use, and such as may be reasonably anticipated." * * *

The first part of these specifications makes it very simple to fix the necessary draft in the canal, as far as the largest vessels now afloat are concerned. With such craft as the *Mauretania, Lusitania, Titanic, Olympic,* etc., requiring more than 38 ft., this figure must necessarily be taken as the actual salt-water draft for which the Canal shall afford convenient passage.

As for the draft that "may reasonably be anticipated" for the future, it is a debatable question which would carry us beyond the limits of this paper, and no one can decide it now with absolute

authority; but a study of the water requirements of an international waterway having permanent locks, would not be complete, from the point of view of true engineering, if due consideration were not given to this most important part of the problem, viz., the probable dimensions of future vessels.

*Probable Dimensions of Future Vessels.*—Taking as a basis of comparison only the period since steam navigation became fully established, it will be found that in 56 years the following increases in the dimensions of steam vessels have taken place:

| | |
|---|---|
| Their beam | 120% |
| Their draft | 132% |
| Their length | 203% |
| Their displacement | 1 607% |
| Their driving power | 3 082% |

A more detailed analysis of the ratio of increase of marine dimensions in the last 25 years only, will show that, if the same gradual average increase be kept for 30 years more, the craft afloat at that time will have dimensions beyond the capacity of even the immense locks now being built at Panama.

With such precedents and a further consideration of the enormously increased facilities for marine construction now at our command, the reduction in the cost of materials, the ever-diminishing ratio of weight per unit of power, the introduction of new metals, new fuels, and new methods for their utilization, added to the well-proven necessity of large units for economy in results, it is permissible to admit that the wonderful gradual development in marine architecture, so marked in these last few years, will not stop just now, when all commercial, industrial, and physical conditions point to the contrary.

For such reasons, the writer believes that, in the not very distant future, commerce will demand, and obtain, for our long-distance trade with the Orient and the South Pacific shores, large freight carriers of low superstructure, wide beam and extreme draft. Such vessels will use the Panama Canal, and this waterway, whether sea-level or lock canal, should be able to meet their requirements when the time comes.

The writer, however, will not presume to predetermine here, even approximately, what the dimensions of such future vessels will be. For the purposes of this paper he will only assume their draft to be at

least equal to that of the largest vessels now on the ways, say 39 ft. 6 in. in salt water, or 40 ft. 8 in. in Lake Gatun.

*Clearance for Safe Navigation.*—In considering the depth of water required for the convenient navigation of a vessel having such draft, the following items must be borne in mind:

*a.*—An ocean vessel will draw from 2½ to 3% more on the warm fresh-water lake of the lock canal than on the seas. For this, an allowance of from 1 to 1¼ ft. must be added to the salt-water draft of a vessel drawing 39 ft.

Congress has stipulated 1½ ft. as the extra requirement for Gatun Lake.

*b.*—In well-protected harbors and docks, where the effects of winds and waves are not felt, a vessel can be made to enter a dock with scarcely 1 ft. of water under her keel; but this demands the greatest of care and the slowest possible speed, and very few navigators would like to assume such risks many times a day.

*c.*—For locks in a canal exposed to wind and wave fluctuations, considerably more clearance is absolutely indispensable. To cross from one ocean to the other in the proposed lock canal, a vessel will have to pass over twenty-six solid sills in the locks and over many miles of solid rock bottoms in the remainder of the route. To reduce this multiple risk, the designers of the locks have, very wisely, provided for a net clearance, which, at the time of their design, amounted to more than 6 ft. over the miter sills, and 4 ft. in the Culebra Cut, where no large fluctuations from waves are to be feared.

*d.*—In a large lake like the one proposed for the Lock-Canal system, measuring more than 30 miles in length and 160 sq. miles in area, northers, gales, and storms may produce at any time waves of considerable amplitude. A steady breeze may "back-up" the waters at one end of the lake and depress them at the other for 1 ft. or more at times. If these conditions should happen to cumulate, the total fluctuation of the lake level may be such as to endanger or interrupt navigation.

*e.*—Preceding considerations show that to permit safe and convenient transit through the Lock Canal, a net clearance of at least 3 ft. in the canal proper and 6 ft. in the lake is needed under the keels of passing vessels.*

* In the Suez Canal, the clearances are restricted as follows: In the narrow channel or canal prism proper 4.86 ft.; in the "Large Bitter Lake" 6.56 ft.; and the canal is incessantly being deepened to maintain such clearances, as the average draft of vessels increases.

*f*.—Any reduction of such clearances will increase proportionately the risks and dangers of navigation through the submerged channels in Lake Gatun, particularly on the rocky bottoms and short navigating "legs" above Bohio, on account of the heavy fogs that will frequently prevail there.

## Available Supply of Water.

On the Isthmus of Panama the meteorological year can be generally divided into two seasons:

The "wet season," lasting from 7 to 9 months; and
The "dry season," lasting from 3 to 5 months.

On the Atlantic side of the Canal Zone, during the "wet season," the rainfall is always abundant, producing an average annual flow of from 8 000 to 14 000 cu. ft. per sec. for the region under discussion; but, during the 3 to 5 months of "dry weather," the rains in that locality cease almost completely, and then the average discharge of all the streams that can empty into the proposed high-level lake at Gatun will rarely exceed 1 100 cu. ft. per sec. in dry years.

TABLE 1.—Rainfall in the Canal Zone, for the Year 1908, in Inches.

This table shows an actual dry season of more than 150 days (5 months); but, in the computations, a dry season of only 120 days has been considered.

| Months. | At Empire. | | At Culebra. | | At Chagres. | | At Rio Grande. | | Average. |
|---|---|---|---|---|---|---|---|---|---|
| | Wet. | Dry. | Wet. | Dry. | Wet. | Dry. | Wet. | Dry. | Dry. |
| July, '07 | 9.85 | ..... | 9.42 | ..... | 9.60 | ..... | ..... | ..... | ..... |
| August | 11.28 | ..... | 11.81 | ..... | 12.20 | ..... | ..... | ..... | ..... |
| September | 10.86 | ..... | 11.36 | ..... | 14.71 | ..... | ..... | ..... | ..... |
| October | 15.44 | ..... | 15.27 | ..... | 13.62 | ..... | ..... | ..... | ..... |
| November | 10.40 | ..... | 6.91 | ..... | 9.85 | ..... | ..... | ..... | ..... |
| December | ..... | 1.47 | ..... | 2.30 | ..... | 2.26 | ..... | 1.66 | ..... |
| January, '08 | ..... | 0.75 | ..... | 0.91 | ..... | 0.20 | ..... | 1.53 | 0.847 |
| February | ..... | 0.00 | ..... | 0.01 | ..... | 0.11 | ..... | 0.00 | 0.030 |
| March | ..... | 0.41 | ..... | 0.13 | ..... | 0.41 | ..... | 0.08 | 0.245 |
| April | ..... | 1.36 | ..... | 1.67 | ..... | 1.81 | ..... | 0.26 | 1.275 |
| May | 12.91 | ..... | 12.63 | ..... | 13.18 | ..... | ..... | ..... | ..... |
| June | 8.21 | ..... | 8.86 | ..... | 6.55 | ..... | ..... | ..... | ..... |
| Totals | 78.95 | 3.99 | 76.26 | 5.02 | 79.71 | 4.79 | ..... | 3.48 | ..... |
| Average | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.599 |

Table 1, showing the rainfall in that central district of the Canal Zone, has been computed from last year's report of the Isthmian Canal

Commission. It gives at a glance a clear idea of these variations in the only source of water supply in that locality.

Records of observations covering a period of more than 20 years give the average annual supply available for Gatun Lake as 8 200 cu. ft. per sec. in dry years, and a dry-season average of 1 200 cu. ft. per sec. for all the region above Gatun.

In 1903, one of the driest years, the discharge at Bohio was as follows:

| | | |
|---|---|---|
| In February, | 1 024 | cu. ft. per sec. |
| In March, | 636 | " " " " |
| In April, | 565 | " " " " |

averaging only 742 cu. ft. per sec., and it has been calculated that the total available water supply for one year in the driest years, for the whole region under discussion may be only about 6 000 cu. ft. per sec. as the average for such a dry year.

For some of these figures on hydraulics the writer is indebted to the remarkably complete work of Brig.-Gen. Henry L. Abbot, on the "Problems of the Panama Canal."

*Storage of Water.*—To overcome the difficulty due to this scarcity of water during the dry season, the designers of the Lock-Canal system propose to impound and store in an artificial reservoir, from the surplus of the wet-season discharge, a volume of water sufficient for all the needs of the Canal during the ensuing dry period.

For this purpose a lake is to be created at Gatun, with an area of more than 170 sq. miles, at an elevation of 85 ft. above the sea. A fluctuation of 7 ft. in the level of that lake would give—during the dry season—an available lake storage of 2 ft. above and 5 ft. below the normal working level of the locks to be fed by it.

On a mean area of 160 sq. miles, the volume of water thus stored would be 31 223 708 000 cu. ft.

This quantity, helped by 1 000 cu. ft. per sec.—the average daily contribution of all the tributary streams discharging into the lake during the dry season—will be the only supply from which the Lock Canal is to be operated, and is thought, by its designers, to be sufficient for all its needs during the 100 or more days of water scarcity.

It is perhaps better to quote here the exact words of the engineers who reported on this important matter to President Roosevelt, on February 17th, 1909.

"It is proposed to fill this lake (Gatun) during the rainy season 2 feet above its normal level, and to draw it as needed during the dry season. It is computed, that by drawing it 5 feet below normal level, which draft would leave 40 feet of water through Culebra cut, the supply in a dry year would be sufficient to serve from 30 to 40 lockages up and an equal number of lockages down daily. Each lockage might consist of a single large vessel, or a fleet of smaller vessels capable of being in the lock at one time. * * * The water supply in sight is so much greater than any need that can be reasonably anticipated that the best method of securing more water when the time of need arrives does not require to be considered now."*

The writer, however, applying to this problem the same study that would be required if it was a commercial proposition, believes that, under the conditions existing, or possible, at Panama, the volume of water thus stored in the lake will prove to be insufficient for the demands of the Lock Canal when its service reaches the duty specified by its engineers in the words above quoted.

To ascertain this, within the limits of an approximate, but safe, estimate, the following computations are submitted.

### Consumption of Water.

In a system of locks fed by an artificial storage reservoir, under the conditions proposed for the Lock Canal, the supply of water must be sufficient to provide for:

I. Surface evaporation,
II. Border evaporation or "fly-off,"
III. Percolation through the bottom and sides of the reservoir,
IV. Water needed for lockages,
V. Normal waste, contingent to lockages,
VI. Water used for hydro-electric plants, at Gatun and Miraflores,
VII. Losses due to leakage at gates and valves,
VIII. Water wasted by maintenance operations,
IX. Losses due to false maneuvers and accidents,
X. Losses of water at spillways and regulating gates,
XI. Miscellaneous losses, local consumption, etc.

*I.—Surface Evaporation.*—It is well known that surface evaporation from water exposed in the open takes place at all times; but those who have had to economize water in regions where this industrial

* Report of Board of Engineers, Feb. 17th, 1909, Document 1458, p. 10.

element is scarce, will remember what a persistent consumer evaporation is, and how difficult it is to measure accurately its activities on a large reservoir.

The "evaporating pans," "atmometers," "evaporimeters," and other instruments of small size that are generally used to gauge daily evaporation are, to say the least, extremely inaccurate, in practice. Any number of them distributed at various stations in a territory covering many square miles will not show, on a given day, the same reading; and their average will not give the actual evaporation on a lake that would cover that same territory. This is due to the different way in which the wind, temperature, and other meteorological elements will affect the convex, rippled surface of a large lake, or the small, confined area of an instrument. On bright, windy days the difference may amount to 25 or 30% in favor of the larger surface because the action of the wind affects the results more than the other causes.

In the tropics, under conditions quite similar to those at Panama, the writer has found surface evaporation during the "dry season" to vary from 0.22 to 0.44 in., according to the month, the temperature of the air and water, the altitude, the barometric conditions, the degree of humidity, the prevalence of winds and fogs, the extension of the surface, and the surrounding locality, it being at the highest either in February or March. In these months, on certain warm days when the moisture in the air is very high, evaporation is much reduced during the hours of calm; but it increases rapidly as soon as the tropical breezes start, reaching sometimes as much as 0.75 in. on very windy, clear days.

In the Gatun district, on account of the exposed condition of the "Zone," the air currents are strong and quite constant, with breezes frequently attaining a velocity of from 8 to 10 and even 32 miles per hour.

Under such conditions, a large lake, with more than 170 sq. miles of warm, shallow waters, swept by such breezes, and exposed to the heat of a tropical sun (125° to 130° in the sun) will certainly have a very high rate of evaporation. And when it is considered that the ripples formed by the wind on the surface of such a vast sheet of water will increase immensely its effective evaporative area, it will be seen that the actual loss on the lake can be considerably more than what would be shown by instruments of small area.

It must be remembered, however, that in the tropics, the large amount of water evaporated from a lake by the combined action of the sun and wind, will produce at times, in the hours of calm, dense fogs during which very little evaporation will take place. Though such fogs, of course, will be more frequent in the rainy season, it is well to anticipate at least a total of 200 or 300 hours of them during the strictly dry months. This will decrease the total evaporation by about 8 or 10%; not enough, however, to counteract the influence of the wind, leaving the average daily loss still above what experimental instruments of small diameter may show, at various stations.

For these reasons the writer believes that the actual daily loss of water by surface evaporation, if it could be measured accurately on the lake, would be found to be much larger than what has been assumed as an average for Lake Gatun, and nearer the following figures:

| | |
|---|---|
| For December | 0.10 to 0.15 in. |
| January | 0.25 " |
| February | 0.29 " |
| March | 0.30 " |
| April | 0.24 " |
| May | 0.10 to 0.12 " |

The average is from 0.24 to 0.246 for the five months of dry weather.

When comparing these figures with others, it is well to remember that in Tables 4 and 6 the actual rainfall on the lake is deducted for each month; and will reduce correspondingly the above apparently high figures.

The writer believes that the system of calculating the evaporation on a reservoir of varying surface, by multiplying its area by the average daily evaporation of the whole year, may produce errors which may be of importance in some localities, when only the dry season is being studied.

*II.—Border Evaporation.*—The lowering of Lake Gatun's level from high to low water, in every dry season, will uncover an area of land measuring more than 100 sq. miles.

Under ordinary conditions, if these "border lands" remain covered with the vegetation which usually grows on river sides in the tropics, and are kept moist, as they will be, by capillarity and by the constant

fluctuations of the water's edge, due to the wind, waves, and other causes; this "fly-off," as it is termed in the West, from these moist borders may reach a considerable amount per day on the 827 miles of shore of that lake, at the temperature which the thermometer will register there in the sun.

After due allowance for drainage, run-off, etc., the water evaporated by this daily uncovering of shores and low lands, may be estimated at 30 cu. ft. per sec.

This, distributed on the lake, will be:

| | | | | | |
|---|---|---|---|---|---|
| For the | 1st | month, | 160 | sq. miles | 0.0066 in. |
| " " | 2d | " | 140 | " " | 0.0076 " |
| " " | 3d | " | 120 | " " | 0.0088 " |
| " " | 4th | " | 100 | " " | 0.0104 " |

*III.—Percolation.*—When a deep storage reservoir is formed on natural ground, there is usually quite a loss of water by percolation through its bottom and sides.

This "seepage" depends principally on the porosity of the soil; the number of seams and fissures (if any); the depth of the water; its temperature; the surrounding locality; the geological conditions, etc. It may vary, in ordinary canals and ponds, from 1 to 4 or more inches per day, measured as a lowering of the water level.

In a large reservoir like the one proposed at Gatun, with more than 200 sq. miles of wetted area, in a region showing varied geological formations and a basin of natural soil, covered in part with tropical vegetation, it is more than prudent to admit that a measurable percolation is possible and quite probable.

Unless the whole 200 sq. miles of that valley be stripped and examined, this probable percolation cannot be estimated in advance, even approximately. Unless every square foot of that vast area is made impervious by artificial means, the loss of water by seepage cannot be authoritatively dismissed as "an impossibility." It can only be guessed at now, and will be ascertained only after the lake is filled. Meanwhile, the question of the possibility of an appreciable amount of percolation through that immense lake bed will remain as one of the most serious risks in a matter upon which depends the ultimate cost and perhaps the success of the whole Lock-Canal proposition.

Under the circumstances, the writer believes that a margin of safety

ought to be assumed against such risks, and that it should be duly proportionate to the importance of the results at issue.

In the absence of experimental data especially applicable to the whole lake basin, an assumption could be based on the following tentative elements:

*a.*—Infiltration area of the lake bed over 200 sq. miles at high water;

*b.*—Depth of water, 85 ft. at high water and shallower at the contours;

*c.*—Top soil covering naturally thicker and more impervious in the lower parts of the bed than in the higher regions above Bohio and at the sides of the basin;

*d.*—Temperature of the stagnant waters in the lake above 90° Fahr. in the shallow parts and about 82° Fahr. in the deeper bottoms;

*e.*—That the foregoing elements are about compensating, leaving the loss of water nearly proportionate to the head, and depending on unknown subsoil conditions;

*f.*—That joints, seams, and fissures are generally abundant in sandstones, conglomerates, and other rocks like those found in the Canal Zone.

*g.*—That the absence of permanent lakes and springs in the whole region strongly indicates either good drainage or ample underground communication with water-absorbing substrata.

Under such assumptions, the writer would consider the empiric rule, $H \times 0.01$, or 0.01 in. per foot of head, a prudent one on which to base a preliminary computation. This, owing to the ever decreasing head of the water in the lake, would give, during a dry season, the following probable depressions:

| | | |
|---|---|---|
| For the 1st month | ..... | 0.4750 in. |
| " " 2d " | ..... | 0.4450 " |
| " " 3d " | ..... | 0.4150 " |
| " " 4th " | ..... | 0.3770 " |

To many, these figures will appear high, and it is hoped that they will prove to be too high; but, without accurate data to the contrary, there is no competent authority to declare them so in advance. It is altogether a question of judgment as to the amount of risk to be taken.

To prove, however, that these figures are based on elements that

deserve some consideration, the following data, published in *The Canal Record* for 1908 and in the Isthmian Canal Reports, may be interesting if not convincing:

"Leaks in the Camacho Reservoir (near Empire in the Canal Zone).

"Leaks in Camacho Reservoir near Empire have made it necessary to draw the water from Elevation 358 to 340 (18 ft.) in order that the fissures in the trap rock of the side hills may be filled with clay. It has been ascertained that the leaks are through the side hills and that the dam is in no way affected."*

TABLE 2.

SEEPAGE FROM SOME WELL-KNOWN CANALS.†

| | Loss of level, per day. |
|---|---|
| Chesapeake Canal | 5.04 in. |
| Chenango Canal | 5.00 " |
| Erie Canal | 5.00 " |
| Morris Canal | 8.50 " |
| Delaware and Raritan Canal | 8.50 " |
| Canal du Languedoc | 2.76 " |
| Canal "Naviglio Ide" | 10.80 " |
| Canal "Martesana" | 18.00 " |
| Hoover ditch, Colorado | 14.40 " |
| Kings River and Fresno | 20.04 " |
| Fort Morgan, Colorado | 60.00 " |

From the report of the very able engineer in charge of the seepage experiments for the foundations of the dam at Gatun, the following data are also obtained:

"Some of the rocks (in the Gatun Valley) are of open texture and permit the flow of water" (page 127).

"The principal water-bearing medium seems to be the joints and seams which cut through the various strata and allow the passage of large quantities of water" (page 127).

"The material has well-defined joint planes and seams through which water passes with velocity enough to throw the stream from 1 ft. to 1½ ft. into the opening" (page 165).

The same authority, as a result of most interesting and carefully made experiments, gives the seepage flow through the Gatun soils experimented upon, and these are collated in Table 3.

* *The Canal Record*, Vol. I, p. 402.

† Report, Isthmian Canal Commission, 1908, p. 196.

TABLE 3.—SEEPAGE VELOCITY IN GATUN SOILS.

| | Feet per second. | Inches per day. |
|---|---|---|
| For clay on 10 ft. head | 0.000028 | 29 |
| For soft sandy rock | 0.000045 | 46 |
| For clay and sand | 0.000083 | 86 |
| Averaging for the three | 0.000052 | 54 |
| For clay and sand, 84 ft. head | 0.000070 | 73 |
| For clay and sand, 85 ft. head | 0.000705 | 731 |
| (The greatest velocity obtained with 34 tests, under 10 ft. head) | 0.000450 | 466 |
| Blue sandy clay, 115.3 head | 0.000193 | 200 |
| Blue sandy clay, calculated on 84.5 ft. head | 0.000014 | 14 |
| Stiff blue clay, calculated on 84.5 ft. head | 0.000002 | 2 |
| Average of these two on 84.5 ft. head | 0.000008 | 8 |

The figures* in Table 3 prove that all the overlying soils and materials experimented upon are sufficiently permeable to allow more than usual percolation.

With such materials, the quantity of water which can disappear through the bottom and sides of that lake will evidently depend on the underlying strata and substrata, their thickness, hydraulic gradients, the presence of fissures, etc., etc. Many of these elements are now unknown, and many are still under investigation; but the testimony taken on this matter—in connection with the foundations for the locks—tends to prove the existence in that locality of substrata through which there is a slow but regular flow of water toward the sea.

In a bed of rock or conglomerate formation that geologists claim has been disturbed three times, there might be more than joints and seams, perhaps fissures and crevices, through which the impounded lake waters may get egress and slowly flow toward the ocean, as they did in the Camacho Reservoir.

In ordinary cases, when dealing with a reservoir having an ample "replenishing supply" to draw from, this matter would not be so important; but in Gatun Lake, all the inflow during the dry season, amounting to only 0.25 in. per day, is scarcely enough to keep up with the evaporation loss alone. Any additional loss becomes a direct draft from the stored supply and is irremediable until the next rainy season.

*IV.—Water Needed for Lockages.*—The conditions under which the Lock Canal is to be operated, according to the proposed plans, are:

* Report, Isthmian Canal Commission, 1908, p. 134.

The locks are to be 110 ft. wide, with the length necessary to admit vessels 1 000 ft. long.

Those at Gatun are to be in flights of three, with an average lift of 28⅓ ft.; those at Pedro Miguel are to have a lift of from 30 to 32 ft.; and those at Miraflores are to be in a flight of two, with lifts of 30 and 40 ft.

These locks will be in duplicate, making twelve chambers in all. Those on one side are to be used for vessels going in one direction; those on the other side for vessels going in the other, or by "double-track navigation."

All craft are to be moved in and out of the locks by special appliances, and will not be permitted to use their own motive power.

No restrictions which would cause delay to boats, such as parking, classifying, etc., will be enforced for the regulation of traffic through the locks.

Safety appliances will be used at every lockage, both for entering and leaving.

It is understood that no other sources of water supply than those now planned, are to be used, and that the two-flight locks at Miraflores will have no other source of water supply, during the dry season, than the tailings from the Pedro Miguel locks on the lake above.

If additional reservoirs at Alhajuela or other points in the catchment basin are established later, or pumping stations are installed to refill the lake from the sea-level sections, they will modify the conditions of the problem. Not having been included in the proposed plans and estimates, these improvements are not considered in the writer's calculations.

*Theoretical "Lockage Water" Consumption.*—The exact volume of water needed for one lockage, under any given condition, can be computed with accuracy; but, in practice, it will vary considerably with the operating circumstances, the working level of the lake, the tides, etc.

The theoretical lockage volume for the upper three-flight locks at Lake Gatun at the 85-ft. level is as follows:

| | | | |
|---|---|---|---|
| Gatun upper lock..... | 28.33 ft. lift.... | 3 614 908 cu. ft. |
| Pedro Miguel..... | 30 " " .... | 3 828 000 " " |
| Total volume at normal 85 ft..... | | 7 442 908 cu. ft. |

These figures do not include any "extras" for the normal waste incidental to the operation of locks, irregularity of service, leakage at gates, valves, etc., nor any correcting coefficient for the larger consumption of the "three-flight" locks.

If this coefficient be applied for the Gatun locks, the volume for one single passage through the lake, in one direction, would be:

| | |
|---|---|
| For Gatun Locks | 4 518 635 cu. ft. |
| For Pedro Miguel | 3 828 000 " " |
| | 8 346 635 cu. ft. |

If the intermediate 600-ft. chambers could be used at Pedro Miguel at every lockage, the volume for one lockage would be:

| | |
|---|---|
| For Gatun Locks, as above | 4 518 635 cu. ft. |
| For Pedro Miguel Lock | 2 508 000 " " |
| For one lockage | 7 026 635 cu. ft. |

But the 2 508 000 cu. ft. then used by the Pedro Miguel Locks will not yield "tailings" enough for the 3 828 000 cu. ft. needed by the "two-flight locks" at Miraflores when these are used full, nor even for the 3 062 400 cu. ft. required if they could also be operated with the intermediate gates for part of the time.

Assuming this, however, to be obtainable sometimes, the lowest consumption that could then be shown would be:

| | |
|---|---|
| For Gatun Locks, as above | 4 518 635 cu. ft. |
| For Pedro Miguel (using enough water to feed the Miraflores Locks, with these working 75% at intermediate chambers) | 3 062 400 " " |
| Minimum volume for one trip | 7 581 035 cu. ft. |

As it may be claimed, however, that great economy of water can be obtained by reducing the coefficient of the "three-flight locks" and by using the Miraflores locks at intermediate gates for 75% of their lockages, particularly during the first years of operations, it is well to know what would be the results under such exceptionally propitious conditions:

Assuming, then, that favorable circumstances would permit the reduction of the lockage coefficient of the Gatun locks to, say, only 1.08, the figure adopted by Gen. Abbot, the lockage water will measure:

| | |
|---|---|
| For Gatun Locks..... | say 3 904 100 cu. ft. |
| For Pedro Miguel Locks, using the volume necessary to operate the Miraflores Locks at 75%..... | 3 062 400 " " |
| Total for one lockage going to Panama.. | 6 966 500 cu. ft. |

The use of the intermediate gates, however, will be objectionable in daily practice, on account of the great number of safety appliances to be used for each craft at each lock, and the necessity of moving all vessels at extremely slow speed by electric capstans, cables, etc., instead of by their own power. Owing to the diversity of operating conditions in these series of locks, it is probable that better service will be obtained if full lockages are taken with several vessels in fleet at one time, instead of using the intermediate gates for each craft.

In considering the capacity of the Canal, the average number of lockages assumed is 20 trips in one direction through one set of locks and 20 trips in the other through the other set, with a consumption of 333 865 400 cu. ft. in 24 hours. It is assumed that any reduction of service in one day will be made up on other days.

The drawing of that amount of water from a lake having, say, 160 sq. miles of surface (the mean area for the first month), will produce a lowering of its level amounting to 0.900 in. per day.

As this daily volume is constant, and the net area of the lake will diminish every day, owing to the lowering of its level, and by the uncovering of islands, slopes, etc., the depth of water lowered every day—or the daily depression of the surface—will increase inversely, giving the following average daily depressions:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| For | 1st | month, | mean | area | of | lake | 160 | sq. miles.... | 0.900 in. |
| " | 2d | " | " | " | " | 140 | " | .... | 1.0285 " |
| " | 3d | " | " | " | " | 120 | " | .... | 1.200 " |
| " | 4th | " | " | " | " | 100 | " | .... | 1.440 " |

These are the theoretical depressions for "lockage water" only. In practice, they will be exceeded considerably. They may also vary

somewhat with changes in the mean areas of the lake, taken here in round numbers, as shown.

*V.—Normal Waste of Water During Lockages.*—With the three different kinds of locks that will be used in the Lock Canal, viz., the three-flight locks of from 28½ to 31-ft. lift at one entrance of the lake; a 30 to 32-ft. single-lift lock at the other, followed by a 35-ft. two-flight lock depending on it for its water supply, it is easy to imagine more than twenty different combinations of conditions which can affect the quantity of water consumed by the passing of a certain number of vessels, as the following few examples will show:

Let $L$ = the net contents of the lock chamber, in cubic feet,
and $B$ = the displacement of a vessel in the lock, in cubic feet.

Then, if, at the Gatun Locks, for an ascending vessel, the lock is found empty, the lockage will cost $3\ L + B$ cubic feet; if the lock is found full, the volume of water used will be only $L + B$ cubic feet, showing a possible variation from single to double.

These Gatun Locks (being in a flight of three, without lateral reservoirs), will not permit advantage being taken of any occasional favorable operating conditions; and, in passing a vessel through them, circumstances may even combine to compel an extra waste of water which could be avoided if they were "single locks."

At the one-flight lock of Pedro Miguel, the water used by vessels passing in train through one lock and returning by the other, will be considerably more than would otherwise be needed, if said vessels could pass ascending and descending, alternately.

In other waterways, great economy of water could be obtained in single locks, like those at Pedro Miguel, by the use of their intermediate locks and also when the level of the lake lowers; but in the Lock Canal, as designed, if such economies were attempted at Pedro Miguel, the "tailings" from its locks would not be sufficient for the supply of the two-flight locks at Miraflores; additional water to complete the consumption of these would have to be furnished, either from other sources, or direct from Lake Gatun.

This explains why no reductions are made for the lowering of the lake, nor for the use of intermediate gates at Pedro Miguel, in the preceding computations.

The foregoing few examples show how important the "normal

waste" can be, and how it depends on varying conditions against which provision must be made. It is true that, by strict regulations, measures may be taken to reduce this waste somewhat, but such a course will produce annoying delays and will be a serious obstacle to free and rapid navigation. In a commercial canal, open to the world's traffic, it will be impracticable to regulate transit so as to secure always the best conditions for economy of water, and some will have to be sacrificed in order to save time or obtain the number of lockages desired.

Under the conditions above analyzed, and probable in the Canal Zone, the efficiency of the system may vary the waste from 10 to 25 per cent.

Supposing that by good management and perfect regulation of the passage of vessels, the "lockage waste" is reduced to only 6.66%, the average daily depression of the lake surface, by this normal waste would be:

| | | | |
|---|---|---|---|
| For the | 1st | month, | 0.0856 in. |
| " | 2d | " | 0.0978 " |
| " | 3d | " | 0.1141 " |
| " | 4th | " | 0.1370 " |

It might be argued that, by having a smaller number of lockages a day, much water could be saved; but this will reduce accordingly the total capacity of the Canal, bringing it below the already too small number of "20 lockages a day," here assumed.

The writer believes that a great tonnage will pass through the Isthmus, not only from other nations but from our own inter-coastal commerce with our Pacific shores and with the Orient. He believes that the Lock Canal in the very immediate future will be insufficient for the demands that will be made upon it; that maximum full lockages with as many vessels crowded in the locks as safety will permit, are the conditions for which to look forward.

If the necessity of saving water does not permit the use of the locks whenever and however needed, without imposing annoying delays and regulations, then the system is insufficient and *per se* inadequate for the requirements of our commerce, of the navy, and of the world at large.

*VI.—Water Used for Hydro-Electric Plants.*—The power needed to operate the twelve locks; to move vessels "in and out" of locks by

electric capstans; to control mechanically the many appliances composing said plants; and to light the canal, will vary considerably, according to the designs adopted, many of which are still under study.

It is intended to use about 6 000 h.p.; part of it to be developed at Gatun and part at Miraflores. It is probable, however, that lack of water will suggest serious alterations in these plans. Mature consideration of this question will prove the necessity of either reducing the hydro-electric plant and locating it all at Gatun or using steam power, unless a dam is built at Alhajuela or other places to store more water and incidentally produce the power.

Assuming that 3 200 h.p. are to be developed at Gatun, the volume of water consumed under an average head of 72 ft. will be 533 cu. ft. per sec.

The lack of water at Miraflores and the irregularities of head due to tides, etc., will make the production of electricity at that spot very uneconomical, as the water will have to be furnished from the lake, and the head available will average only 50 ft. The production of 2 800 h.p., under such conditions, will imply a consumption of 667 cu. ft. per sec., bringing the total water used by the hydro-electric plants, for net power only, to 1 200 cu. ft. per sec.; this is without including the usual allowances for waste.

In Tables 4 and 6 the two plants are shown separately, with a total consumption of 1 200 cu. ft. per sec.

The resulting lake depressions for each pumping station will be:

| | | | |
|---|---|---|---|
| For the | 1st | month, | 0.1392 in. |
| " | 2d | " | 0.1591 " |
| " | 3d | " | 0.1856 " |
| " | 4th | " | 0.2227 " |

With a dam at Alhajuela, this item would disappear from the Lake Gatun budget, while additional storage would be secured, without increasing the high-water level on the lake, and the corresponding "operating oscillations," which are already too great for safe and convenient handling of craft in the locks.

*VII.—Losses Due to Leakage at Gates and Valves.*—The gates and valves in the proposed locks will have dimensions never before attained in lock construction.

The steel gates will have leaves more than 80 ft. high and 65 ft.

wide, weighing perhaps 500 tons each. The locks on Lake Gatun will have 44 of such leaves, and more than 80 operating valves exceeding perhaps 10 ft. in diameter, with their corresponding seats and joints under pressure.

It will be almost impossible, in practice, to keep such ponderous appliances absolutely tight, and a considerable "normal waste" must be expected and allowed for. Even the most improved appliances, if fitted too tightly, could not be operated with the speed that lock service requires. The lock gates when new, must be built with a clearance of at least 1½ in. in order to allow for future wear; and it may be said that a perfect condition of tightness in them could never be maintained long, if it is ever attained.

This normal leakage may vary from 8 to 12% of the lockage water under the best conditions of practical equipment.

Taking only 8%, or 295 cu. ft. per sec., the daily depressions produced on the lake will be:

| | | | |
|---|---|---|---|
| For the | 1st | month, | 0.0684 in. |
| " | 2d | " | 0.0782 " |
| " | 3d | " | 0.0912 " |
| " | 4th | " | 0.1095 " |

*VIII.—Water Wasted by Maintenance Operations.*—The enormous amount of "metal work" forming the active parts of the locks, which will be almost continually in contact with water, will demand, in the Canal Zone, incessant care, repeated cleaning, scraping, painting, and other special protection against the tropical elements. Much of this work must, necessarily, be done during the dry season only.

With perhaps more than 30 000 tons of movable lock gates; miles of submerged pipes, culverts, joints, cables, chains, safety appliances, etc.; with more than 80 immense "by-pass," "sluice," and "auxiliary" valves; with four enormous rolling gates, bumpers, their operating appliances, and submerged tracks, and with miles of masonry walls, it is prudent to admit the probability of many compulsory stoppages for running repairs and for maintenance. In many cases, it will be possible to employ divers, but in others it will be necessary to empty the locks and sacrifice the large quantities of water they contain.

Admitting that, when possible, all renewals, running repairs, flushings, etc., are left for the wet season, and that only unavoidable losses

will be permitted during the season of scarcity, it seems that an allowance of 65 cu. ft. per sec. would be a conservative figure to cover these contingencies. To this must be added the amounts chargeable to the power plants and hydraulic motors operating on Lake Gatun, making together about 125 cu. ft. per sec. The corresponding depressions on the lake will be:

| | | | |
|---|---|---|---|
| For the | 1st | month, | 0.0290 in. |
| " | 2d | " | 0.0316 " |
| " | 3d | " | 0.0385 " |
| " | 4th | " | 0.0460 " |

In considering these figures it is well to bear in mind that the locks will be forever in continual use, with no "long dead seasons" during which complete overhauling could be undertaken. It may be claimed that the locks, being in duplicate sets, could be emptied at any time for general overhauling. This is true; but the safety appliances and towing devices now arranged for "double-track" service, will make "single-track operation" very dangerous, and will reduce considerably the tonnage capacity of the canal, when attempted.

The repairs will have to be made when needed, and as often as needed. Hence the apparently large allowance for this contingency.

*IX.—Losses Due to False Maneuvers and Accidents.*—With the many protective features now under study for these locks, and the many regulations that will have to be enforced on the passing vessels, no serious accidents in the locks are anticipated. The jamming of gates and valves by floating débris; the occasional breaking of a valve spindle or gate trunnion; some mishap at the rolling gates; perhaps some trouble at the water-wheels, are the most probable causes of some extra loss of water, which, with care, can be reduced to a minimum.

Even with the best of management, however, false maneuvers will be a constant source of danger, and will cause great waste of water, particularly when handling foreign craft with crews not familiar with the service, and at night in locks of unprecedented dimensions, where the oscillations of the working level will be at times considerable, and the signaling distances very long.

Accidents, however, can be predicted, but not estimated; that they may happen is now too well proven by the very serious one of June, 1909, in the Sault Ste. Marie Lock, when three vessels were sunk and

the lock put out of commission after losing enormous quantities of water.

To cover only normal contingencies, a margin of 125 cu. ft. per sec. is taken, giving the following lake depressions:

| | | | |
|---|---|---|---|
| For the | 1st | month, | 0.0290 in. |
| " | 2d | " | 0.0316 " |
| " | 3d | " | 0.0385 " |
| " | 4th | " | 0.0460 " |

That these figures are conservative will perhaps be admitted, if the following data are analyzed:

The delays to navigation in the Poe Lock on account of breakages have been reported as follows:

In a total of 2 007 days of operation in the single Poe Lock at St. Mary Falls, Mich., there have been 1 104 hours of stoppage due to breakages, as follows:

| | |
|---|---|
| Gate engines | 282 hours. |
| Gate cables | 145 " |
| Sheaves for cables | 44 " |
| Obstructions against miter sills | 37 " |
| Grounding on platforms | 26 " |
| Fouling of tow-lines | 26 " |
| Jamming of vessels | 12 " |
| Gates | 204 " |
| Pressure pipes | 48 " |
| Gratings | 6 " |
| Changes in pressure system | 249 " |
| Miscellaneous | 25 " |
| Total | 1 104 hours. |

These were only current repairs during operation.

In the Poe Lock, all "necessary" repairs and overhauling of the lock and machinery are always made every winter when the canal is not in service, the foregoing delays being only for "accident" repairs.

If this is the case for only one lock having only 4 gates and a 20-ft. lift, what will be the figures for 12 locks of larger sizes with 30-ft. lifts, 84 gates three times larger, in continual use, and performing a duty seven times larger, under conditions much more unfavorable? This

leaves out of consideration the additional contingencies due to the spillways, rolling bumpers, auxiliary drawbridge dams, capstans, and towing appliances, not used at all in the Poe Lock.

*X.—Losses at Spillways and Regulating Gates.*—The regulating appliances at the spillways must be, by construction, extremely strong and of ample size, so as to be able to resist the enormous discharges of "flood times."

The "spillway" at Gatun will be more than 800 ft. long, with 21 steel gates, each 38 ft. wide and with 16 ft. of water depth. In order to be operated easily and quickly, these active parts cannot be made, in practice, to fit too tightly; hence this source of leakage, being continual, may amount to very considerable figures.

For the normal leakage at these extra large regulating gates, it would not be good practice to take less than 200 cu. ft. per sec. for the conditions that will prevail in the Canal Zone; but, allowing for the gradual lowering of the lake level, and to avoid criticism, 125 cu. ft. per sec. is taken as the average loss.

The corresponding depressions will be:

For the 1st month, 0.0290 in.
" 2d " 0.0316 "
" 3d " 0.0395 "
" 4th " 0.0000 "

*XI.—Miscellaneous Losses.*—As the lake will absorb and control all the streams of the central region of the Canal Zone, for miles around, it must in return furnish water, directly or indirectly for:

*A.*—All the needs of the populations and industries that may locate around its borders, and on its numerous islands;

*B.*—The consumption and replenishing of all passing vessels and craft using the lake; and

*C.*—All the losses and wastes at the intermediate section from Pedro Miguel to the sea-level section at Miraflores, due to evaporation, percolation, fly-off, etc.

For all these losses 300 cu. ft. per sec. is assumed, giving the following depressions:

For the 1st month, 0.0464 in.
" 2d " 0.0536 "
" 3d " 0.0615 "
" 4th " 0.0742 "

It will be observed that in the foregoing computations, many of the figures are debatable, being matters of judgment. That is why such lengthy and tedious reasonings have been given in order to state the grounds on which these figures are based. If the estimated losses of water are too large, any economy realized on them after the canal is built will be a clear gain from which to draw for future enlargements of the service.

The writer believes that, in questions of such importance, any approximation on the safe side is better than a "poor guess," and, in consequence, he submits his figures only to invite discussion on the debatable points.

The remote possibility that a lake created at an enormous expense and on which depends the whole Lock-Canal system, might not be up to its estimated capacity when finished or later, merely for lack of water, deserves, at least, to be well studied by civil engineers.

## Replenishing Water Supply.

The only replenishing supply for Lake Gatun—after the last rain of a wet season has fallen—is, as has been stated, what it will receive from all the tributary streams that empty into it, plus whatever occasional rain may fall on its surface.

Records show that the available supply from these two sources will rarely average more than 1 200 cu. ft. per sec., and that this may be considerably less in "dry years."

In these computations the local precipitation has been considered separately, and the corresponding monthly amounts have been credited to the lake each month, as shown in Tables 4 and 6; the rainfall of 1908 is taken as an example, being the latest available, but by no means the driest.

As the plane of drainage discharge in that Chagres-Gatun Valley will be raised 87 ft. above its original level on an area of 170 sq. miles, the part of the dry season's inflow corresponding to the drainage of a great part of that area will disappear from the lake's budget, thus reducing to that extent the amount of "dry weather" replenishing inflow.

That being the case, if figuring on the driest years, the inflow from all tributaries above the lake could be taken at 1 000 cu. ft. per sec. for the months of scarcity; but the writer has assumed that a remnant

of the rainy season run-off will overlap into the beginning of the dry season and increase the average of its first month's flow to about 1 500 cu. ft. per sec.

This will give a "dry season" average of 1 217 cu. ft. per sec., and add to the lake level as follows:

For the 1st month, 0.3466 in.
" 2d " 0.2118 "
" 3d " 0.2790 "
" 4th " 0.4810 "

In the extra dry years which occur at intervals, the foregoing amounts will be considerably less after deducting the precipitation on the lake, etc.

TABLE 4.—LAKE DEPRESSIONS DURING THE DRY SEASON: 20 ROUND TRIPS.

| Losses. | DAILY DEPRESSIONS OF THE LAKE LEVEL, IN INCHES. | | | |
|---|---|---|---|---|
| | 1st month, 160 sq. m. | 2d month, 140 sq. m. | 3d month, 120 sq. m. | 4th month, 100 sq. m. |
| I. Surface evaporation | 0.2500 | 0.2900 | 0.2950 | 0.2500 |
| II. Border evaporation | 0.0066 | 0.0076 | 0.0088 | 0.0104 |
| III. Percolation | 0.4750 | 0.4450 | 0.4150 | 0.3770 |
| IV. Lockage water only (20.) | 0.9000 | 1.0285 | 1.2000 | 1.4400 |
| V. Normal waste for traffic | 0.0856 | 0.0978 | 0.1141 | 0.1370 |
| VI. Hydro-electric plants, Gatun | 0.1392 | 0.1591 | 0.1856 | 0.2227 |
| " " " " Miraflores | 0.1392 | 0.1591 | 0.1856 | 0.2227 |
| VII. Leakage at gates and valves | 0.0684 | 0.0782 | 0.0912 | 0.1095 |
| VIII. Water used for maintenance | 0.0290 | 0.0316 | 0.0385 | 0.0460 |
| IX. Losses by false maneuvers, etc | 0.0290 | 0.0316 | 0.0385 | 0.0460 |
| X. Losses at spillway | 0.0786 | 0.0480 | 0.0395 | 0.0000 |
| XI. Miscellaneous losses | 0.0696 | 0.0804 | 0.0922 | 0.1112 |
| Total losses per day, in inches | 2.2702 | 2.4569 | 2.7040 | 2.9725 |
| Credit daily inflow, average 1 100 cu. ft. per sec | 0.3466 | 0.2118 | 0.2790 | 0.4810 |
| Net depression per day, in inches | 1.9236 | 2.2451 | 2.4250 | 2.4915 |
| Loss of draft per month, in inches | 57.71 | 67.35 | 72.750 | 74.745 |
| Credit, rainfall on lake (1908) | 0.84 | 0.30 | 0.245 | 1.275 |
| Net loss by months, in inches | 56.87 | 67.05 | 72.50 | 73.47 |

*Total loss of draft in canal during one Dry Season.*

| | | | |
|---|---|---|---|
| After 30 days | 56.87 in. | = 4.74 ft., | say 4 ft. |
| " 60 " | 123.92 " | = 10.32 " | " 10 " |
| " 90 " | 196.42 " | = 16.36 " | " 16 " |
| " 120 " | 269.89 " | = 22.48 " | " 22 " |
| (year 1908) " 150 " | 343.36 " | = 28.61 " | " 29 " |

TABLE 5.—RESULTS OF ONE DRY SEASON'S OPERATIONS (20 TRIPS), STARTING WITH LAKE FULL, UP TO + 87-FT. MARK.

| | Depression. | USABLE SALT-WATER DRAFT LEFT IN CANAL (3%). | | | |
|---|---|---|---|---|---|
| | | Absolute. | 3 ft. clearance. | 4 ft. clearance. | 6 ft. clearance. |
| Beginning of dry season.... | 0.00 ft. | 45.59 ft. | 42.60 ft. | 41 ft. | 39 ft. |
| After 30 days..... | 4.74 " | 41.00 " | 38. " | 37 " | 35 " |
| " 60 " ..... | 10.32 " | 35.59 " | 32.60 " | 31 " | 29 " |
| " 90 " ..... | 16.36 " | 30.56 " | 27.36 " | 26 " | 24 " |
| " 120 " ..... | 22.48 " | 24.79 " | 20.79 " | 19 " | 17 " |
| " 150 " ..... | 28.61 " | 17.84 " | 14.84 " | 13 " | 12 " |

The Isthmian Records show many years of more than 150 days dry weather.

Table 5 shows that:

After the first month of operation, the contemplated 41-ft. draft in the Canal will have disappeared.

After 60 days, vessels drawing 33 ft. cannot use the canal with safety.

" 90 " " " 28 " " " " " " "

" 120 " " " 21 " " " " " " "

" 150 " " " 15 " " " " " " "

TABLE 6.—LAKE DEPRESSIONS DURING THE DRY SEASON: FOR 30 ROUND TRIPS.

| Causes. | DAILY DEPRESSIONS, MEASURED IN INCHES. | | | |
|---|---|---|---|---|
| | 1st month, 160 sq. m. | 2d month, 140 sq. m. | 3d month, 120 sq. m. | 4th month, 100 sq. m. |
| I. Surface evaporation..... | 0.2447 | 0.2828 | 0.2950 | 0.2400 |
| II Border evaporation..... | 0.0066 | 0.0075 | 0.0088 | 0.0105 |
| III. Percolation..... | 0.4750 | 0.4450 | 0.4150 | 0.3770 |
| IV. Water for lockages only..... | 1.2834 | 1.4667 | 1.7112 | 2.0544 |
| V. Normal waste by lockages..... | 0.0856 | 0.0978 | 0.1141 | 0.1370 |
| VI. Hydro-electric plants..... | 0.2784 | 0.3182 | 0.3712 | 0.4454 |
| VII. Leakage at gates and valves..... | 0.1368 | 0.1564 | 0.1824 | 0.2180 |
| VIII. Water used for maintenance..... | 0.0490 | 0.0600 | 0.0600 | 0.0900 |
| IX. Losses by false maneuvers..... | 0.0296 | 0.0316 | 0.0385 | 0.0460 |
| X. Losses at spillway..... | 0.0780 | 0.0283 | 0.0000 | 0.0000 |
| XI. Miscellaneous losses..... | 0.0695 | 0.0804 | 0.0922 | 0.1112 |
| | 2.7366 | 2.9737 | 3.2884 | 3.7795 |
| Less daily inflow..... | 0.3466 | 0.2127 | 0.2884 | 0.4895 |
| Net depression per day, in inches..... | 2.3900 | 2.7600 | 3.0000 | 3.2900 |
| Loss of level per month, in inches..... | 71.70 | 82.80 | 90.00 | 98.70 |
| Credit rainfall..... | 0.84 | 0.30 | 0.30 | 1.30 |
| Net depression per month ..... | 70.86 | 82.50 | 89.70 | 97.40 |

| | | | | |
|---|---|---|---|---|
| Total loss of level in | 30 days | ..... | 70.86 in. = | 5.90 ft., say 6 ft. |
| " " " " after | 60 " | ..... | 153.36 " = | 12.78 " " 12 " |
| " " " " " | 90 " | ..... | 243.06 " = | 20.10 " " 20 " |
| " " " " " | 120 " | ..... | 340.46 " = | 28.37 " " 28 " |

*Total loss of draft in canal during one Dry Season.*

| | | | |
|---|---|---|---|
| After 30 days' operation | ..... | 70.86, say | 6 ft. |
| " 60 " " | ..... | 153.36 " | 12 " |
| " 90 " " | ..... | 243.06 " | 20 " |
| " 120 " " | ..... | 340.46 " | 28 " |

TABLE 7.—RESULTS OF ONE DRY SEASON'S OPERATIONS (30 ROUND TRIPS), STARTING WITH LAKE FULL, UP TO + 87-FT. MARK.

| | Depression. | USABLE SALT-WATER DRAFT LEFT IN CANAL. | | | |
|---|---|---|---|---|---|
| | | Absolute. | 3 ft. clearance. | 4 ft. clearance. | 6 ft. clearance. |
| Beginning of dry season..... | 0.00 ft. | 45.60 ft. | 42.60 ft. | 41.60 ft. | 40 ft. |
| After 30 days..... | 6.00 " | 39.77 " | 36.77 " | 35.77 " | 32 " |
| " 60 " ..... | 12.00 " | 33.95 " | 30.95 " | 30.00 " | 28 " |
| " 90 " .... ..... | 20.00 " | 26.19 " | 23.20 " | 22.20 " | 21 " |
| " 120 " ..... ..... | 28.00 " | 18.43 " | 15.40 " | 14.43 " | 12 " |

Table 7 shows that:

After the first month of operation, the contemplated 40-ft. depth of water will have disappeared from the Canal.

After 60 days, vessels drawing 31 ft. cannot navigate the canal.

" 90 " " " " 24 " " " " "

" 120 " " " " 16 " " " " "

## RÉSUMÉ.

A résumé of all the foregoing computations is shown in Table 4, for 20 trips a day, with the corresponding results for one dry season's operations.

As it has been claimed that the capacity of the Lock Canal could be enlarged at any time later, or whenever needed, by the construction of additional locks alongside of those under discussion, it is not idle to ascertain now whether the visible supply of water above the lake would permit such enlargements.

For that purpose Tables 6 and 7 have been prepared for 30 trips only, and assuming that, with the additional lockage facilities greater economy of water could be obtained.

They show that, if additional locks were built and a double service attempted, the consumption of water would lower the lake and leave

only a 19-ft. draft. This would make it impossible to use the canal while that rate was kept up, unless some system of pumping and re-pumping the water back from the sea into the lake were established, at an onerous and perpetual expense.

The tables prove also that the Lock Canal, by construction and by insufficiency of water, is forever limited to less than the 20 round trips taken as a basis in this study, on account of the resulting reduction of the navigable draft, if a larger service were maintained.

It is admitted, of course, that even this small rate will not be reached during the first years of operation; but the Canal is to serve forever. What the requirements of commerce will be, in years to come, is beyond an engineer's computation; history, however, shows that all ways of communication created by man have had to be enlarged, in order to satisfy the ever-increasing requirements of successive generations.

The Lock Canal, as now being built, can never be enlarged, as it could not be operated if enlarged, on account of mere lack of the necessary water.

In a sea-level canal, fed at each end by the ocean, this problem of water supply is completely and forever eliminated.

The sea-level canal can thus be at any time enlarged to meet any possible requirements of navigation in the future, for its water supply, being unlimited, need never be considered.

## Deductions.

Tables 4 and 5, for 20 trips, tend to prove:

1.—That after 60 days of dry weather, the large vessels now afloat and all the men-of-war of the navy drawing more than 33 ft. cannot use the canal, on account of lack of depth.

2.—That after 90 days of dry season, all naval vessels, transports and craft drawing more than 28 ft. could not navigate Lake Gatun.

3.—That after 120 days, no vessel drawing more than 21 ft. can use the canal.

It may be argued that only the large transatlantic transports draw more than 37 ft., and that they will probably never cross the Isthmus. They are, nevertheless, now afloat; and other semi-carriers are now being completed that will draw 41 ft. on Lake Gatun.

In case of war, these and the largest transports will be the very

ones impressed for the service. If they cannot pass the Isthmus except at the end of the rainy season, an enemy could very well choose the proper time to strike us when the Lock Canal is incapacitated by mere lack of water in Lake Gatun.

### Conclusions.

The foregoing deductions prove:

1.—That the water supply as planned for the Lock Canal will be insufficient and inadequate for the most important service for which the Canal is being built: the use of the United States Navy.

2.—That this insufficiency of water limits for all time the capacity of the Lock Canal to less than 20 round trips a day.

3.—That all the available water supply above Lake Gatun is not sufficient for a larger service, and thus makes impossible any enlargement of the Lock Canal in the future.

4.—That under the present plans the 40-ft. draft expected to be obtained in the canal cannot be maintained.

---

In closing this paper, the writer is aware of the fact that arguments and figures may be produced in its discussion which may apparently prove that his conclusions are not justified, but he wishes to record here his opinion that unless the existing supply of water is augmented by the construction of additional reservoirs and pumping stations, not called for by the present plans, the Lock Canal cannot be operated on the basis now contemplated.

# DISCUSSION

Mr. Grunsky

C. E. GRUNSKY, M. AM. SOC. C. E.—In an article on the type of the Panama Canal,* prepared by the speaker in January, 1909, attention was called to the water requirements of the Canal, as estimated by the Board of Consulting Engineers of 1905, on the basis of figures furnished by General Henry L. Abbot, of the Corps of Engineers, U. S. Army (Retired). At that time it was stated that these figures required revision because, after the estimates had been made, the actual area of Gatun Lake was found to be 164 sq. miles instead of 110, as assumed, and because, in the meantime, it had been determined to widen the canal locks to 110 ft. Further discussion of this important feature of the Canal problem by the Canal authorities has not come to the speaker's notice.

Mr. Sorzano's paper is timely because, although it is now too late for a material change of canal plan, it would be unfortunate if proper measures were not taken to bring the lock canal to the highest state of efficiency.

The speaker is among those who were disappointed when the report of the Board of Consulting Engineers—eight to five—was set aside, and the lock canal was adopted. Locks are not added to canals to improve them. They are, however, oftentimes necessary in order to adapt a canal to the physical peculiarities of the available canal route. Where there is a choice between an adequate canal without locks and one with locks, the question to be answered is whether the better canal is worth the additional cost in time and money. In the case of the Panama Canal this question has never been answered conclusively. The Board of Engineers of 1905, with the data then available, told President Roosevelt that the additional cost of a sea-level canal was justified. The Canal Commissioners, who, in the light of more complete data, might have taken up the question again as late as 1908, seem to have been content to place before Congress and the American people evidence that the Gatun Dam can be made a safe structure, but they failed to furnish convincing evidence that the better canal would not have been worth the additional cost. Moreover, in the light of the favorable progress reports relating to the excavation of the canal prism, it is reasonable to believe that the excess cost would not have been as great proportionately as was originally assumed.

When the American engineer is asked why the United States did not build a first-class canal, he will be at a loss for a satisfactory answer. Nor is it likely that conclusive evidence on this point will ever be furnished by anyone. The time has passed when it was essential to study the larger problem, and, in any discussion, under comparison

* *Popular Science Monthly*, May, 1909.

Mr. Grunsky.

with the accomplished results, the sea-level canal, with difficulties of conjectural magnitude, would be likely to fare badly.

It seems to be taken for granted that a dam at Alhajuela would safeguard the water supply. The speaker has been at the Alhajuela dam site, and was impressed by the lack of adequate information relating to the geological formations at that point. Exhaustive studies may have been made since that time. At any rate, this word of caution against accepting the Alhajuela site as the best, without full investigation, will not be amiss. At Gamboa, where it would have seemed natural and reasonable to construct a dam, with spoil from Culebra Cut, to an elevation of about 200 ft. above sea level, there is good conglomerate foundation, the lowest point of which is about at sea level. This was satisfactorily demonstrated by borings in 1904. It may still be possible to construct a dam at this point. The Gamboa Reservoir, with a water surface of more than 30 sq. miles, would be a most excellent regulator of the flow of the Chagres River. If this dam had been constructed at once (1905-1907), it would have solved numerous water-supply problems, and would have furnished power for many uses along the line of the Canal. Perhaps a dam can be constructed at this point after the lock canal is in service, but this does not seem likely, because the dam site will be submerged by the waters of Gatun Lake to a depth of about 40 ft. If the work already done has not made this dam impracticable—construction with spoil from Culebra Cut being assumed—the advisability of constructing it at once should receive more than passing consideration by the Canal authorities. If, upon a revision of the author's figures, it be found that a shortage of water is to be feared, a decision should at once be reached with regard to the location of the additional storage reservoir. This decision should not be postponed until what, at present, seems to be the best site has been rendered impracticable.

As one of the engineer members of the Isthmian Canal Commission of 1904-1905, the speaker had hoped to have an opportunity of studying and passing upon all the larger engineering problems which the construction of the Canal involves, but this hope was not realized, and since his brief connection with the work, time and opportunity for a comprehensive study of these problems could not be found. Lacking complete information, yet being frequently credited with its possession, it is always with some misgivings that he participates in the discussion of the Canal problems. He wishes to avow himself deeply interested in the success of the Canal, though venturing some criticism.

The water-supply estimates presented by the author are demonstrable in part only. The quantity of water required for lockages, the leakage at structures, the water required for power, the rainfall, and the evaporation from the water surface of the lake can be estimated with some degree of precision from known facts; but the loss of water

Mr. Grunsky.

from wet marginal lands and the loss by infiltration from a lake of large extent are matters of conjecture, in which there is wide latitude for personal opinion. Would it not be better, therefore, to estimate the available supply—the known flow of the streams, the water available from storage, and the rain on the lake's surface—and to deduct from this the losses by evaporation from the lake, leakage at the structures, and a definite allowance for power, and see what remains? The remainder will be the water available for lockages and for the indeterminate losses by marginal evaporation, by seepage, or otherwise. These losses may turn out to be small. Perhaps it will be safe to assume no loss by evaporation from marginal wet areas, because this loss is offset by the gain resulting to the flow of the streams by the elimination of the swamps and wet areas at present within the lake contour above Gatun, for which the author has made no allowance. The loss of water by infiltration and all other indeterminate losses can then be introduced into the calculation as personal judgment may dictate.

The Canal capacity, as determined by the water supply, on the extreme assumption that such indeterminate loss is too small to be considered, cannot be exceeded except by drawing more water from storage. A draft of more than 5 ft. on Gatun Lake, as pointed out by Mr. Sorzano, would reduce the effective depth of the Canal, unless storage be provided elsewhere than in Gatun Lake.

Using for illustration such data—not verified—as are at hand, it would appear that:

| | | |
|---|---|---|
| The low-water flow of streams entering Gatun Lake during four dry months will average about | 1 200 | sec-ft. |
| The water obtainable from storage in Gatun Lake, 5 ft. (87 to 82 ft.), for the same period, will amount to | 2 210 | " |
| The rain on the lake's surface, about 2.60 in. during four dry months, will be | 100 | " |
| Total | 3 510 | sec-ft. |

There will be required:

| | | |
|---|---|---|
| To supply the evaporation loss, 0.0215 ft. in depth per day, from 164 sq. miles | 1 140 | sec-ft. |
| To supply leakage at structures | 250 | " |
| For power, and other uses | 200 | " |
| Total | 1 590 | sec-ft. |

There is, of course, some uncertainty relating to the loss of water by evaporation. Experiments made at Boston, Mass., and at Kingsburg,

Mr. Grunsky.

Cal.,* indicate that, for a mean monthly temperature of 78.5° Fahr., which is about that which will prevail during the dry months at Gatun Lake, an evaporation of 0.0215 ft. per day may be expected from an open water surface. This is about 7% in excess of the evaporation rate assumed by General Abbot in 1905. Canal Commissioner H. H. Rousseau, Assoc. M. Am. Soc. C. E., in an address before the Trans-Mississippi Congress in August, 1909, places the evaporation loss at $\frac{1}{7}$ in. per day, but does not state how he arrives at this amount.

For a mean monthly temperature of 78.5°, the Boston curve indicates an evaporation rate of 0.021 ft. in 24 hours. The highest observed points on the Boston curve are for mean monthly temperatures of 72° and 70° in July and August, and corresponding relative humidities of about 71.5 and 75.5 per cent.

The Kingsburg curve indicates a rate of 0.022 ft. for a mean temperature of 78.5 degrees. The highest points on this curve, based on observation, are for mean monthly temperatures of 82° and 84°, in July and August, with corresponding relative humidities of 32 and 35 per cent.

On the Isthmus the mean monthly relative humidity during the dry months is about 84 per cent. It seems probable that the actual evaporation rate from a large body of water on the Isthmus, owing to the high moisture content of the atmosphere, will be somewhat less than the rate introduced into the calculation; but a satisfactory basis for a humidity correction is lacking.

The leakage at structures, above noted, is the estimate of the Board of Engineers of 1905. The requirement for power has also been introduced into the calculation at the Board's estimate. The present plans contemplate the use of much more water for power, but this is immaterial, as, in case of need, all available water would be used for lockages during the dry months and none at all for power, which can always be otherwise secured.

According to the above figures, on the assumption that the lake is full at the beginning of the dry months, there would be available for lockages and to supply the seepage and other indeterminate losses, 3 510 — 1 590 = 1 920 sec-ft. On the extreme assumption of no seepage loss and no allowance for evaporation from marginal wet lands, all of the 1 920 sec-ft. would be available for lockages.

Following General Abbot's method of estimating the quantity of water required per lockage, on the assumption that a reduced lock length will be used for 80% of the lockages, the average requirement per lockage per day through the Canal would be about 55 sec-ft. According to Mr. Sorzano, each lockage per day will require 96 sec-ft. It is probable, of course, that the Canal will be used for some time as

* "Evaporation from the Salton Sea," by C. E. Grunsky, M. Am. Soc. C. E., *Engineering News*, Aug. 13th, 1908, p. 163.

Mr. Grunsky.

assumed by General Abbot, but the possibility must also be admitted of a demand on the Canal to its capacity within comparatively few years. This capacity may be limited by the number of lockages that can be made per day, or by the number for which water is available. The maximum traffic, expressed in tonnage and not by the number of lockages, will undoubtedly be attained when the locks are always crowded full of shipping and no lockages are made with intermediate gates. By the method of estimating used by the Board of Consulting Engineers and by General Abbot, there should be required for each such lockage through the canal 6 900 000 cu. ft. of water, or 80 sec-ft. for 24 hours.

The available water, therefore, would permit of 35 lockages per day, if 80% are lockages with intermediate gates. On the author's assumption of the requirement per lockage through the canal, there would be water for 20 lockages per day. As the Board of Engineers would estimate (intermediate gates not used), there should be water enough for 24 lockages per day when the demands of commerce have reached the canal capacity. If no water were used for power, these figures might be increased by 4, 2.5, and 2, respectively.

The maximum traffic through the Canal, as limited by the speed with which vessels can be passed through the locks, is given at 40 per day by Alfred Noble, Past-President, Am. Soc. C. E., and Joseph Ripley,* M. Am. Soc. C. E. It is 48 according to Mr. Rousseau,† who probably voices the opinion of the Canal authorities. Messrs. Noble and Ripley place the extreme number at 57, but state that, after allowing for all causes of delay, it should not be hoped to realize more than 40.

These numbers are far in excess of the 20 to 24 lockages estimated from the water supply. The water supply, in other words, does not appear to be sufficient to bring the canal up to the tonnage capacity of the locks without utilizing more storage than is now contemplated. Each additional foot below the 82-ft. level drawn from Gatun Lake will add about 4.5 to 5.5 lockages per day during a period of 120 days, this number depending on whether the net contents of the locks, or the figures suggested by Mr. Sorzano, should be introduced into the calculation.

Any seepage losses from Gatun Lake will reduce the number of lockages by one per day for each 80 to 96 sec-ft. of such loss. That there will be some such loss seems unquestionable. If it should approximate the amount suggested by the author—about 1 960 sec-ft.—it would indeed be a serious matter. The writer sees no cause for alarm. He believes that this loss will be small, and that it should only be considered as one of the elements of risk which, in some measure, may

* Report to the Board of Consulting Engineers of 1905.
† Address at Denver, in August, 1909, before the Trans-Mississippi Congress.

Mr. Grunsky.

reduce the efficiency of the lock canal. The distance which must be traversed by percolating waters from Gatun Lake to any outfall point, except near the various dams, is so great that the velocity of motion will be very slow. The measured losses of water from canals, as cited by Mr. Sorzano, can only be used as evidence that seepage losses are possible; they afford no criterion of the amount of such loss from a lake of large extent. The measurements in the case of the Kings River and Fresno Canal, referred to in the paper, were made by the speaker. The canal lies in a flat alluvial territory, and the seepage was but a few feet vertically downward to the water-table.

The available data indicate that the traffic capacity of the Panama Canal, during the dry period, will be limited by, and is to be determined from, the available water supply. The best method of holding the water supply throughout the year at the capacity of the locks is, therefore, a matter which should receive timely attention.

Mr. Hodges.

H. F. HODGES,* M. AM. SOC. C. E. (by letter).—Mr. Sorzano's paper on the probable water supply for the lock canal at Panama is most interesting. The conclusions he reaches are so different from those of others who have reasoned from the same data, that the writer feels impelled to join in the discussion which he so kindly invites.

The author's remarks on the requirements of navigation admit of no convincing contradiction. Anyone is at liberty to prophesy on this subject. The dimensions which are now fixed for the locks of the Panama Canal, and the depth which has been given to its channels, express the judgment of the authorities responsible for these features as to the probable future needs of navigation. If the draft of vessels desiring to use the Canal should grow beyond its depth, however, it may be said that, not only the Canal, but the great majority of harbors now available, would have to be deepened in order to accommodate these monster vessels; and that the cost of deepening the Canal and renewing its locks would be only a small part of the expense to which mankind would be forced by such a development.

The clearance which Mr. Sorzano regards as necessary (6 ft. below the keel in a reasonably good channel), seems a little large, and his requirement of 3 ft. below the keel in a lock is unquestionably more than is needed. Large vessels pass through the St. Marys Falls Canal drawing practically every inch of water which the elevation of the sill will permit, and sometimes, strangely enough, a little more.

Table 1 is possibly a little misleading in its reference to the actual and the assumed dry season. It is true that the actual number of rainless months on the Isthmus sometimes exceeds the ordinarily assumed length of the dry season, but as far as its effect on the water supply of Lake Gatun is concerned, this is not important. The rivers

* Lt.-Col., Corps of Engineers, U. S. Army.

continue to run with much more than their ordinary dry-season flow for some time after the rains have ceased, so that if a rainless season of 5 months is assumed, there would only be a season of 4 months of minimum water supply in the lake. These periods, of course, are given in round figures, but they will justify Mr. Sorzano in assuming in his computations a dry season of only 120 days, although indicating one of more than 150 days in Table 1. Mr. Sorzano, however, has overstated his case in saying that "the average discharge of all the streams that can empty into the proposed high-level lake at Gatun, will rarely exceed 1 100 cu. ft. per sec. in dry years." The minimum daily average for the 4 months of the dry season, namely, the average in the worst known dry season for 19 years is 1 190 cu. ft. per sec., and the average dry season has a daily average discharge of 3 030 cu. ft. per sec. For the 3 driest months, the discharge is less, but the quantity stored in the lake, if distributed over 3 months instead of 4, would more than make up the difference. Mr. Hodges.

It is in its assumptions as to the consumption of water that the paper differs most from discussions which have led to the usual belief in the adequacy of the water supply. The assumption as to surface evaporation is somewhat greater than that which experience on the Isthmus seems to justify. The average evaporation for the dry months, shown by observations, is 6.6 in. per month for the 3 driest months, and 6.026 in. when the dry season is considered 4 months long. In the remaining months of the year it is approximately one-half of this. Mr. Sorzano's assumption of $\frac{1}{4}$ in. or more per day is somewhat in excess of the actual determined amount. The writer, however, believes that a credit to the water supply of considerable moment has been overlooked. The contribution to the waters of the lake during the dry season is the discharge of the Chagres River and its tributary streams. Its stated amount has been estimated, not from the rainfall and catchment area, but from the measured discharge of the rivers in the dry months. During these months, as well as during the rainy months, the area which will eventually lie under the water of the lake is now covered by a dense growth of lush vegetation, which, even in the dry season, draws up and gives off to the air a tremendous amount of moisture which never appears in the measured discharge of the rivers. It is known that the amount so given off by growing vegetation may reach approximately the figures assumed for the evaporation. This loss will cease when that from evaporation comes in. In debiting the lake with evaporation from its surface, one should not forget to credit it with the unknown amount by which the river flow is now reduced through the medium of vegetation growing over the lake bed. No fixed value has been attributed to this amount in any discussion of the lake supply. It has been held simply as an indefinite although considerable reserve.

Mr. Hodges.

Mr. Sorzano's evident respect for border evaporation, or "fly-off," indicates that he will probably be sensible of the importance to be attached to this reserve.

In connection with border evaporation, Mr. Sorzano states that the drying up of the lake "in every dry season, will uncover an area of land measuring more than 100 sq. miles." This, of course, depends on how much of it dries up. The area of the lake, at + 87, is 167.4 sq. miles, and at + 80, is 153.3 sq. miles. The writer's studies lead him to believe that it will not dry up even as far as the latter reference, and if it does, Mr. Sorzano's area of 100 sq. miles will be reduced to less than 14 sq. miles. In the average dry season the writer believes that the lake will not shrink noticeably.

As for the percolation through the bottom and sides of the reservoir, the author admits that it can only be guessed at, and the writer gives cordial assent to that proposition. Efforts to determine it, however, have not been lacking. The gentleman whom Mr. Sorzano compliments as being a very able engineer, and from whom he quotes as to certain experiments for the foundations of the dam at Gatun, has also made quite extensive borings at different portions of the rim of the reservoir area and of its bed, in places where the configuration and geological formation of the soil indicated that such investigations were most necessary. The result of these investigations has not shown any area which can be regarded as dangerous, and has strengthened the confidence of the engineers on the Isthmus that the percolation through the bed and walls of the reservoir will not be a matter of serious importance. In reference to this matter, the fact is worthy of notice that the Camacho Reservoir, to which Mr. Sorzano alludes as a horrible example of the permeability of Isthmian rock, supplies, from a water-shed of about 1 sq. mile, a total of about 2 000 000 gal. daily. This amounts to a flow of 3.1 cu. ft. per sec., aside from all losses due to evaporation, percolation, "fly-off," and what-not. Such a flow over the water-shed tributary to Lake Gatun, after deduction for the losses mentioned, would leave about 4 000 cu. ft. per sec. available, an amount greatly in excess of any probable need.

The author's discussion of the consumption of water in lockage requires a little correction. Owing to the fact that the upper lock in the Gatun and Miraflores flights is, for certain reasons, somewhat larger in area than the lower ones, the lifts between the upper and lower pools at these localities are not divided equally among the locks, and, at Gatun, the normal lift of the upper 1 000-ft. lock will be 26.38 ft., when the lake is at + 85 and the sea below at mean level. The lift of the other two 1 000-ft. locks at Gatun will be 29.31 ft. each, at the same water stages. At Pedro Miguel the normal lift will be 30 ft. at lake levels of 85 and 55, and, at Miraflores, the normal lift of the upper 1 000-ft. lock, with the lake at + 55 and the sea at mean tide, will be

Mr. Hodges.

26.10 ft., while the lift of the lower lock will be 28.90 ft. These figures will alter somewhat the lockage prisms assumed by the author.

Neglecting losses by leakage, etc., the total draft on the summit level, due to the passage of a vessel through the Canal, should be two prisms of lift and no more. These two prisms are those in the upper locks at Gatun and at Miraflores, and since, for reasons which will appear later, the opportunity of saving water at Pedro Miguel is so much greater than at Miraflores, the latter place will rule the water consumption. The displacement of the vessel, although mentioned by Mr. Sorzano, does not have any influence on the net result of a complete passage. It increases the consumption for a vessel going up and decreases that for one on its downward lockage. Neither of the two prisms of lift which each passage takes from the lake, however, must, of necessity, be a full prism; and that leads to an investigation of the statement, inferentially accepted by Mr. Sorzano, that intermediate gates cannot be used to advantage in the three-lift flight at Gatun. This statement crept into the Report of the Board of Consulting Engineers of 1905, and, apparently, has received circulation and acceptance since. The writer craves indulgence for an endeavor to prove its fallacy.

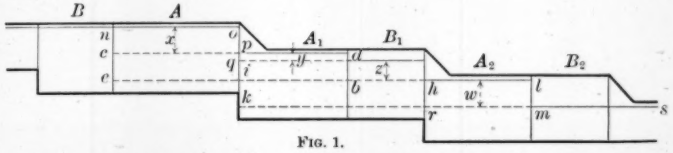



FIG. 1.

In considering the operation of the twin flight of locks, it should be remembered that it is intended to reserve one flight for up-bound and one flight for down-bound vessels. The water in each lock of the up-bound flight will regularly be left at its high level, and in the down-bound flight, regularly at its low level. Let Fig. 1 represent a three-lift flight of locks, each divided, as are those proposed for Gatun, into two unequal parts by intermediate gates, *n-e*, *d-b*, and *l-m*. Let the chambers, $A$, $A_1$, and $A_2$, be equal in area, and call this area $A$, and represent the area of the lock, $B_1$, by $B$. Suppose a vessel to have passed down, using the 550-ft. locks; then, since it must pass from lock $A_1$ to $A_2$, through $B_1$, and the gate, *g-r*, must then be shut to lower the boat to sea level, it follows that the level in $B_1$ as well as in $A_1$, after the downward passage of the vessel, will be the high level of the lock $A_2$. Represent the lift between the high levels of successive subdivisions, as follows:

$$B \text{ to } A = o;$$
$$A \text{ to } A_1 = x;$$
$$A_1 \text{ to } B_1 = y;$$
$$B_1 \text{ to } A_2 = z;$$
$$A_2 \text{ to sea} = w.$$

Mr. Hodges.

Fill $A$ to lake level, $n$-$o$, and admit the vessel; close the barrier $n$-$e$. Then, since the level in $A_1$ and $B_1$ is the high level of $A_2$, represented by the line, $e$-$l$, the total quantity of water above that level, $e$-$l$, in the two locks, $A$ and $A_1$, before equalizing, is represented by the prism, $n$-$e$-$i$-$o$. If, now, keeping the gates and valves in the barriers, $n$-$e$ and $d$-$b$, closed, the valves in the barrier, $o$-$i$, be opened, the water level, $n$-$o$, in $A$, and, $i$-$b$, in $A_1$, will equalize at $p$-$d$. The prism, $c$-$e$-$b$-$d$, which is now above $e$-$l$, must be equal to the prism, $n$-$e$-$i$-$o$, which was above that level before equalizing. From this we have, since $o$-$p$ is equal to $x$, $p$-$q$ to $y$, and $q$-$i$ to $z$, and the areas of $A$ and $A_1$ are equal:

$$A\ (x + y + z) = 2\ A\ (y + z);\ \text{hence},\ x = y + z \ldots\ldots\ldots (1)$$

Since the barrier at $d$-$b$ was kept closed, the level in $B_1$ during this operation has remained at $b$-$h$. Let the vessel now be passed into the lock, $A_1$, and the gate and valves in $o$-$k$ be closed. In $A_1$ and $B_1$ the total prism above $b$-$h$ is $p$-$i$-$b$-$d$, equal to $A\ (z + y)$. Open the valves in $d$-$b$ and the water levels in $A_1$ and $B_1$ will equalize at some level, $q$-$g$, the total prism above $b$-$h$ now being $q$-$i$-$h$-$g$, equal to $(A + B)\ z$. Equating these two prisms, we have:

$$A\ (y + z) = (A + B_1)\ z;\ \text{hence}\ z = \frac{A\ y}{B} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Now open gate, $d$-$b$, and the valves in $g$-$r$, and equalize the levels between the combined chamber $A_1$-$B_1$, and the chamber $A_2$ in which the water level is at the line, $r$-$m$. Equalization will take place at some level, $h$-$l$, at a distance, $w$, above sea level, and, by the reasoning already followed, we have the prism, $q$-$k$-$r$-$g$, equal to the prism, $i$-$k$-$m$-$l$, or,

$$(A + B)\ (z + w) = (2A + B)\ w;\ \text{hence}\ A\ w = z\ (A + B) \ldots (3)$$

Combining Equations 2 and 3, we have $w = \frac{y}{B}(A + B) = \frac{A\ y}{B} + y$.

Combining Equations 1 and 2, we also have $x = \frac{A\ y}{B} + y$; hence $x = w$. We find, therefore, that $x$, which we know to be equal to $y + z$, is also equal to $w$, and consequently, that the lifts between consecutive 550-ft. locks are the same. Now admitting the vessel to the chamber $A_2$ and closing the barrier $g$-$r$, the water in $A_2$ can be lowered to sea level through the valves in $l$-$m$, and the vessel passed out through $B_2$ with the total loss of the prism, $h$-$r$-$m$-$l$, which is $A\ w$, and equal to the prism, $A\ x$, originally taken from the upper level. The levels in the flight will be left as found.

In order to accomplish the result it is necessary only that after the vessel has been admitted from the combined lock chamber, $A_1 + B_1$, to the 550-ft. lock chamber, $A_2$, closed below by the barrier $l$-$m$, the barrier $g$-$r$ should be closed behind it before it is lowered from the level, $h$-$l$, to sea level. In this way the vessel drawing full draft can be passed

Mr. Hodges.

through the flight with only the expenditure of water due to the prism of area $A$, or the 550-ft. lock, and the height, $x$, or $y + z$, or $w$, equal to one-third of $A$. The lock, $B_1$, becomes practically a portion of an intermediate canal, the water level never going below the normal high level in $A_2$, or $h$-$l$. There is no necessity for making two operations, as indicated above, of lowering the vessel from $p$-$d$ to $h$-$l$. The valves in $d$-$b$ and $g$-$r$ may be opened at once, allowing the prisms in $A_1$ and $B_1$ to flow simultaneously into $A_2$, thus avoiding a slight loss of time.

If one takes the up-bound instead of the down-bound flight, the locks will regularly be found full, but the reversal of the operation will lift a vessel of suitable size from the low level to the high level with only the expenditure of one 550-ft. prism of lift, and without necessitating diminution in draft or delay in transit. A similar discussion will show that even the smaller 350-ft. lock may be used, with a very small expenditure of water, in locking small vessels through. The operation is somewhat more complicated, as the lock flight is divided into more lifts in order to accomplish this end, but the lifts are lessened and the time of each lockage, therefore, is made shorter; so that, while the lockages would be increased in number, it is doubtful if any increase in the time of passage would result. The saving of water through the use of the smaller locks is continuous as long as the series of small lockages remains uninterrupted. Under certain circumstances, the interruption of the series by a vessel requiring the full size and full depth nullifies the saving due to one of the previous lockages.

The writer feels that he owes an apology for the length of the foregoing demonstration, but he has thought it necessary in view of the general acceptance of the statement that intermediate gates cannot be used to advantage in the three-lift flight.

There is also another means of saving lockage water, of which Mr. Sorzano had probably no information. The middle walls of the locks are designed so that communication, controlled by valves, can be opened between the twin-lock chambers, and one can be used as a reservoir for a portion of the prism of lift in the other. A lockage in one direction may then require only a portion of the normal prism, leaving the remainder stored up for use in the upper twin lock of the other flight. Such saving in case of the flights is possible only with vessels which do not require the full draft of the normal prism over the sills, but it is very evident that the great majority of vessels will be of this description, especially those which can pass through the smaller locks. The possible saving due to this cross-storage of water is greatest at Pedro Miguel, where there will be no loss of depth by cross-filling, and where, under the most favorable circumstances, 50% of the lockage water can be saved, and under ordinary circumstances a quantity varying between 25 and 50 per cent. It is less at Gatun where the maxi-

Mr. Hodges.

mum possible saving is about 24%; and it seems safe to count on about 15 per cent. At Miraflores, the saving should be intermediate between that at Gatun and at Pedro Miguel. The existence of this possible saving is the ground for the previous statement that the expenditure of water will be ruled by Gatun and Miraflores, rather than by Gatun and Pedro Miguel.

Mr. Sorzano may be correct in his opinion that the development of commerce will lead to the use of the large locks with a number of vessels, instead of the small locks with one or two ships. If this be the case, each lockage will mean several passages instead of one or two, and the net result to commerce will be approximately the same. Each one of the fleet lockages will take a longer time than the one involving a single vessel, and, consequently, there will be fewer of them in the course of the 24 hours.

It is difficult to foretell just what line of development commerce will take. When the Poe Lock at St. Marys Falls Canal was designed, its dimensions were based on the methods of Lake carriage then existing, with one steam barge and a number of tow barges, it being intended to take in, as far as possible, one entire tow, two ships abreast. Methods of carriage on the Upper Lakes have changed since then, the large single vessel having come to the front; and if the lock were to be built now, less attention would be given to taking in a fleet of relatively small vessels two abreast, and more to taking in two large vessels tandem. The canal on the American side at "The Soo" now averages approximately one and one-half boats per lockage.

The author's intimation that the use of the intermediate gates will be objectionable on account of the great number of safety appliances to be used for each vessel at each lock, and the necessity of moving all vessels at extremely slow speed, can apply only to the use of the 350-ft. lock. No more movements are necessary in locking with the 550-ft. lock than with the 1 000-ft. lock. As stated before, however, when the small 350-ft. lock is in action, the method of operation may be such as to increase the number of lifts in order to save the greatest possible quantity of water. Nevertheless, it is not necessary that the number of lifts should be increased, even with this small lock, unless full draft is needed, and, even should it be thus increased, the lifts themselves are correspondingly diminished, the time of each lockage is correspondingly reduced, and, furthermore, the small size of the vessel will render its movement from lock to lock more easy and rapid. The writer is not inclined to accept, without reserve, the general statement that the use of the intermediate gates will be attended by delay, believing that the reverse will be the case.

The author's estimate of the water used for hydro-electric plants indicates that he has been misled by the knowledge that the Commis-

sion is now building two generating plants at Gatun and Miraflores. Apparently, he has assumed that it is intended to generate the full power at these two localities, and, therefore, he has stated that "it is intended to use about 6 000 h.p." Mr. Hodges.

The present intention is to develop for operation somewhat less than 2 000 h.p., and this at Gatun. Ordinarily, the Miraflores plant is intended to lie idle, and only a part of the Gatun plant is to be in use. During the period of construction it is necessary to have the two plants, and, using steam, to develop a power considerably greater than is contemplated for the operation of the Canal in after years, when the power will be developed by water. The calculations which have been made on the Isthmus as to the water supply assume an expenditure of 275 cu. ft. per sec. for the permanent development. After the Gatun plant begins to supply the operating needs, the Miraflores plant, which will still have auxiliary boiler capacity, will be held in reserve ready to be thrown into the line in case of any failure. Having boilers installed, steam can be used should it be found desirable for any reason, in which case the estimated expenditure of 275 cu. ft. per sec. from the lake will cease.

In the author's discussion of the losses due to gates and valves, he has been rather hard on the Canal. It is true that the Gatun locks will have 40 gate leaves and a great number of valves, but there are only 4 gate leaves and 3 sets of culvert valves there through which the lake will lose water. The others will have their own leakage supplied by the leakage from above. If it be assumed that there is an opening $\frac{1}{32}$ in. wide around the meeting faces of the effective gates and valves, the leakage at Gatun will not reach half the amount mentioned by Mr. Sorzano. The assumptions made on the Isthmus as to the leakage through gates and valves, including the spillway, give a combined total of 275 cu. ft. per sec. for both ends of the upper level.

Any conclusions as to the water to be wasted in maintenance operations (Cause VII in the paper), must be largely guesswork. Undoubtedly, however, most of the intentional operations which will involve waste of water can be made to occur during the rainy season, when the loss is of no consequence. The writer cannot possibly accept the author's claim that 125 cu. ft. per sec. must be chargeable to these operations, including the power plants and hydraulic motors operating on Lake Gatun. If these plants and motors are private property, it will be a very simple matter for the Government to stop any draft of water should it be found desirable. It is not part of the duty of the Canal to supply them. If, on the other hand, the author refers to the Government plant, that has been reckoned in elsewhere.

The author's statement that the safety appliances and towing devices, now arranged for double-track service, will make single-track operation

Mr. Hodges.

very dangerous, does not appear to the writer to be justified. Single-track operation of a flight of locks is undoubtedly less convenient than double-track operation, but the safety appliances and towing devices, to which the author alludes, introduce into the single-track operation no element of danger not present in the double-track operation. The twin flights of locks are intended to be entirely independent of each other in this regard.

The author's Cause IX, "Losses due to False Maneuvers and Accidents," is also a matter of speculation. He mentions, however, the 1 104 hours of stoppage due to breakage at the St. Marys Falls Canal, Mich., during its 2 007 days of operation, as an indication of the amount of water loss which may be expected in the Panama Canal. There is no statement of how much water loss at "The Soo" was involved by these hours of delay. From the best of the writer's information, he is inclined to believe that there was considerable time lost, but very little water.

The losses at the spillways and regulating gates of the Panama Canal can be controlled to a certain extent. The discharge over the spillway is to be regulated by crest gates about 19 ft. high, under the lower edge of which the flow will take place. When these gates are closed, it does not seem to be impracticable to pack the vertical edges and sill in such way that there will be little, if any, leakage, even under the 16-ft. head to which they will be exposed.

The author's Cause X, "Miscellaneous Losses," also seems to the writer to be somewhat overdrawn. Among these losses he includes all the needs of the population and industries which may locate around the borders of the lake and on its numerous islands. The population of the country during the construction of the Canal is very much greater than it was before, and the needs of this increased population are now adequately supplied by reservoirs which lie either above the level of Lake Gatun or are not tributary to it at all, and the waters impounded in these reservoirs are not counted in the estimated lake supply. If these reservoirs prove insufficient for future consumption, they can be supplemented by others which will store wet-season water for dry-season use, without affecting the dry-season supply for Lake Gatun. Mr. Sorzano also mentions the consumption and replenishing of all passing vessels and craft using the Canal. If this prove a source of inconvenience, the vessels can be made to get their water supply elsewhere, as they do now, and as they would have to, were the Canal to be built at sea level.

He also mentions the losses and waste at the intermediate section from Pedro Miguel to the sea-level section at Miraflores, due to evaporation, percolation, "fly-off," etc. Of course, there will be evaporation from the small lake at Miraflores, but it also has certain small inde-

Mr. Hodges.

pendent sources of supply which are greater in proportion to its area than those of Lake Gatun. It need not draw on the latter to supply its losses by evaporation, etc.

Assuming the area of Lake Gatun at 164 sq. miles, and the depth of storage available, as stated by Mr. Sorzano, at 7 ft., namely, from + 80 to + 87, the total volume of water thus stored is equivalent to a flow of 3 090 cu. ft. per sec., for 120 days. Adding this to the minimum supply of 1 190 cu. ft. per sec. gives a total supply of 4 280 cu. ft. per sec. available for all uses during the dry season of 4 months, without drawing the lake down below + 80.

The observed rate of evaporation during a dry season of 4 months is equivalent to a flow of 930 cu. ft. per sec. for the lake area. In his calculations, the writer has assumed the leakage at the gates and valves at 275 cu. ft. per sec.; seepage, waste, etc., at 85 cu. ft. per sec.; and lighting, power, etc., at 275 cu. ft. per sec. In this assumption, as well as in Mr. Sorzano's, the credit due to saving in the lake the quantity of water which is now poured out by the vegetation covering its bed has been neglected, and the element of percolation in the bed, which is entirely unknown, has been omitted. The quantity of water required for lockage has been obtained by the following assumptions, which may or may not prove to be justified in fact. The writer gives them for what they are worth.

TABLE 8.

| (1) Lock. | (2) Area. | (3) Normal Lift. Gatun. | (3) Normal Lift. Miraflores.* | (4) Total water for complete passage, in cubic feet. | (5) Column 4; in cubic feet per second. | (6) Weight. | (7) Column 5 weighted. | (8) Saving due to cross-filling. | (9) Column 7 corrected for Column 8. |
|---|---|---|---|---|---|---|---|---|---|
| 1 000 ft..... | 133 800 | 26.38 | 26.10 | 7 022 000 | 81.5 | 5% | 4.08 | 16% | 3.42 |
| 900 ft..... | 122 800 | 28.10 | 27.40 | 6 810 000 | 78.9 | 15% | 11.83 | 16% | 9.93 |
| 550 ft..... | 82 400 | 28.33 | 32.75 | 5 033 000 | 58.3 | 50% | 29.15 | 15% | 24.77 |
| 350 ft..... | 40 400 | 18.58 | 30.16 | 1 969 000 | 22.8 | 30% | 6.84 | 11% | 6.08 |
| Totals..... | ..... | ..... | ..... | ..... | ..... | ..... | 51.90 | ..... .. | 44.2 |

* No intermediate gates in lower lock at Miraflores.

The plan of the upper lock is such that lengths of 1 000 ft., 900 ft., 550 ft., or 350 ft. can be used, the 550-ft. and 350-ft. lengths being capable, by squeezing, of increase to about 600 ft. and 400 ft., respectively. In preparing Table 8, the assumption has been made that 5% of the vessels arriving would require the 1 000-ft. lock; that 15% would require the 900-ft. lock; that 50% will pass in the 550-ft. lock, and the remaining 30% in the 350-ft. lock. With these assumptions, and taking into consideration the saving in water which can be effected by cross-

Mr. Hodges.

filling, the total average consumption for one passage per day, *i. e.*, for two prisms of lift each day, is 44.2 cu. ft. per sec. Neglecting any advantage to be derived from cross-filling, it is 51.9 cu. ft. per sec. Deducting the sources of loss assumed above from the total available supply would give 4 280 — 1 535 = 2 745 cu. ft. per sec., which, at the calculated value for cross-filled lockage, will allow 48 complete passages of the Isthmus per day with a remainder of 623 cu. ft. per sec. as a margin. The writer believes this margin to be sufficient to cover underestimate of losses, and feels confident that the water supply will prove adequate to the needs of the Canal for a great many years, if not for all time to come. Should it ever become necessary to increase it, this can be done very simply by the construction of a dam on the Upper Chagres River, at Alhajuela or elsewhere, which will permit of increased storage to supply the deficiency during the dry season. The duty of building this dam may be properly left to posterity, should the need ever arise.

The foregoing estimate of the water supply is based on the minimum observed daily average for the 4 dry months, *viz.*, 1 190 cu. ft. per sec. The daily average supply for the average dry season of 4 months is much greater, being 3 030 cu. ft. per sec. In the average year, therefore, the surplus will be greatly increased.

In the foregoing, as in Mr. Sorzano's paper, a 7-ft. storage, from + 80 to + 87 in Lake Gatun, has been assumed. In the recent plans, the storage has usually been taken at only 5 ft., from + 82 to + 87, and even with this reduced variation in level, it is thought that the supply is sufficient for all lockages through a dry season of minimum flow. In other words, instead of the lake level being reduced, as concluded by Mr. Sorzano, it will not be necessary to bring it below + 82, giving a depth of 42 ft. in the Culebra Cut, under the most unfavorable circumstances. For many years it may be held desirable to operate at a lower level, until vessels requiring the full draft desire to use this route; but, in the writer's judgment, there will be no necessity, due to scarcity of water, for such low-level operation.

Mr. Paschke.

THEODORE PASCHKE, M. AM. SOC. C. E. (by letter).—The author has treated his subject most ably. His conclusions are startling, and if, after a full discussion, they still prove to be approximately correct, they are a severe arraignment of the designs for this great work.

Of the various items affecting the water supply of the Canal, Cause III, "Percolation through the bottom and sides of the reservoir," has attracted the writer's particular attention, as it embraces a feature which has not been mentioned in the paper, and, apparently, has been overlooked by Mr. Sorzano.

The author's deduction that the water level of the lake will suffer a certain lowering during the 4 months of dry season, by percolation or seepage through the bottom and sides, is based on certain assump-

tions of the existence of fissures and seams in the rock formations and the general porosity of the subsoils in the locality, all of which in turn have been the subject of close scrutiny, investigation, tests, and other researches by the Canal engineers. These assumptions, therefore, are fair and are not to be gainsaid. Mr. Paschke.

For the sake of argument, it is also admitted that the deductions therefrom—the amount of seepage—will conform to the conditions existing when the reservoir is first being filled. From that time, sedimentation will take place all over the bottom and sides of the lake, and attention is called to this feature. If the writer is not misinformed, the soils which overlie the rock formation of the Isthmus are composed mainly of volcanic deposits. These soils yield easily to the erosive action of running water resulting from the torrential downpours peculiar to the rainy season in the tropics.

In a stream like the Chagres, having its origin in a mountainous region overlaid by such volcanic deposits, the flood waters are charged to their capacity with the eroded particles of the soil. The finer particles, held in suspension, are never deposited along the sides or bottom of the stream, but, impelled by the current, are carried out to sea to furnish material for new combinations and formations in Nature's great workshop. In cases where the flood waters overflow the banks of the stream into adjoining and comparatively level regions, where the flow of the waters is arrested, the suspended matter is slowly deposited, thus forming, in the course of time, a well-nigh impervious layer over these stretches, constituting the basis for the swampy character of regions which otherwise, due to their elevations, should drain themselves.

Only the coarser and washed particles carried by the flood waters are found deposited in old and new river beds. The opinion is here ventured that the low hills of the Gatun region consist of such washed-out material deposited from time to time by the flood waters of the Chagres. This would explain the high seepage flow through some of the Gatun soils given in Table 3.

By throwing the artificial barrier across the Chagres Valley at Gatun, the waters of that river will be impounded and form a lake. The effect will be that all the sediment brought down by the flood waters during the rainy season will be deposited in this lake. The coarser and heavier particles will be deposited at the point where the flood waters come in contact with the lake water, and the lighter and finer particles will be carried a little farther before they settle to the bottom. The lightest and finest particles, however (the volcanic dust particles in combination with organic matter held in suspension), will be diffused throughout the waters of the lake, reaching every nook and corner, where they will gradually settle to the bottom. This process of settle-

Mr. Paschke.

ment of the finer particles will go on with more or less uniformity throughout the rainy season, which lasts about 8 months of the year.

It is not difficult to foresee the final result, provided the Gatun Dam stands and does not slip and disintegrate (as predicted by some), or is not washed out on account of some ramming accident at the locks (as predicted by others).

Granted that the soils forming the sides and bottom of the proposed lake are porous and that the underlying rocks are shattered, full of seams and joints, and that for these reasons the lake bed, at the beginning, will be nothing more than an immense filtering bed, surely the sedimentary deposits from the Chagres and other inflowing streams will eventually choke up the filtering features and ultimately seal effectively every pore, seam, and joint in the material forming the bed. Indeed this whole process is nothing more than a gradual filling up of the lake with the spreading of a water-proof blanket over the bottom and sides in advance of the coarser filling material.

The views here advanced are not born of a desire merely to criticize, but represent the conclusions reached during a professional experience of 12 years in one of the Central American States, during which the writer had ample opportunity for observing similar phenomena in reservoirs, lakes, and rivers.

In conclusion it should be stated that these views should not be taken as a defense of the present designs of the great work. Any possible modification of the author's calculations, due to any tendency to retard and check the percolation of water from the lake, will be so slight as not to affect in the main his general conclusions, which, in the writer's opinion, stand unimpaired. They are an appeal not only to engineers, but also to the whole American people, to pause and think a moment over the possibility of having the traditional national reputation for sagacity come to naught by any short-sightedness displayed in the persistence of the present designs of a lock canal.

Mr. Hazen.

ALLEN HAZEN, M. AM. SOC. C. E. (by letter).—The writer will discuss only one feature of this paper, namely, the loss of water by percolation. The author's assumptions as to percolation differ radically from those which the writer has made, and the difference represents the greatest single difference between his calculations and the hydraulic calculations which were used in making the Report of the Consulting Engineers in February, 1909, to which the author refers.

Under the heading "Seepage Velocity in Gatun Soils," reference is made to certain experiments by C. M. Saville, M. Am. Soc. C. E., Assistant Engineer of the Commission. From this report the author has derived conclusions which differ from the writer's, and it seems best to take up these experiments in somewhat greater detail. The

Mr. Hazen.

experiments on soils are described on page 138, *et seq.*, of the Report of the Isthmian Canal Commission for 1908.

The soils were placed in galvanized-iron tanks, 39.36 in. in diameter, and 54.5 in. high. The tanks were coated inside with pitch and coarse sand. In the center of the bottom a connection was made which was protected by a piece of wire screening. Two $\frac{3}{4}$-in. pipes, with perforated cross-pieces, were carried through the sides of the tanks and embedded in the material to be tested. These were connected on the outside with pressure gauges in which the differences in head were observed. The water passing was collected and measured. As far as possible, an effort was made to deposit the material in the tanks in a condition similar to that when found in place. Every effort was made to drive out all the air from the material, and a constant head of water was maintained.

The discharges under conditions when the hydraulic slope equaled 1, or, in other words, when the head available to make water pass through was equal to the depth of the material, for the five materials tested, were as follows:

| | Cubic feet per acre per 24 hours. |
|---|---|
| Stiff blue clay from test pit down the Chagres River, north of the dam site | 49.9 |
| Red sandy soil from embankment slope of spillway hill | 226.7 |
| Medium fine sand from test pits down the Chagres River | 206.7 |
| Brown sandy clay from Gatun Island test pit, between surface and 13 ft. below | 136.4 |
| Blue sandy clay from Gatun Island test pit, from 15 to 37 ft. below surface | 295.7 |

Mr. Saville did not reduce these to inches per day, but the writer has done this, with the following results, for the five materials, respectively:

0.014,
0.062,
0.056,
0.037,
0.081,

average, 0.050, equal to $\frac{1}{20}$ in. per day.

In applying these results to the probable percolation of water from Gatun Lake, allowance must be made for the probable difference in hydraulic slope. Certainly the average distance from the water in the lake through the ground to a point where it could discharge outside would be a considerable number of miles. For the purpose of this calculation, assume that it is only 1 mile, and that the discharge in

Mr. Hazen.

all cases is at sea level. There will then be a head of 85 ft. acting in a distance of 1 mile, or a slope of 1.62% in place of 100 per cent. By a well-known law of percolation, the rate of seepage will be reduced in the same proportion as the slope, and the percolation to be expected will be $0.05 \times 0.0162 = 0.0008$ in. per day.

This rate of seepage is not to be reckoned necessarily on the whole area of the bottom of the lake. It applies instead to the smallest section of the pervious material through which the water is obliged to pass on its way from the lake to the sea. There is no means of determining what this smallest section would be; certainly it would be only a fraction of the actual area of the lake. It is needless to attempt to determine it, because even if the rate be applied to the whole area of the lake, it amounts to less than $\frac{1}{1000}$ in. per day, or to the one six-hundredth part of the amount assumed by the author.

Mr. Saville's experiments with rocks, made by cementing a piece of rock into a 6-in. pipe, represent more difficult and perhaps less conclusive investigations. The results, for 1 ft. in thickness of stones, scaled from Plate 103, accompanying Mr. Saville's report, are given in Table 9.

TABLE 9.

| No. | Kind of stone. | Source. | Head, in feet. | Percolation, in cubic feet per square foot per hour. | Computed Percolation, in Inches per 24 Hours. | |
|---|---|---|---|---|---|---|
| | | | | | Head equals slope. | 85 ft. head in a distance of 1 mile. |
| 1 | Blue sandstone | Lock site.. | 4 | 2.0 | 144 | 2.3 |
| 2 | Volcanic ash | Lock site.. | 40 | 2.2 | 16 | 0.27 |
| 3 | Volcanic tufa | Quarry.... | 40 | 0 | 0 | 0 |
| 4 | Dark conglomerate | Lock site.. | 40 | 0.01 | 0.7 | 0.011 |
| 5 | Brown conglomerate | Lock site.. | 40 | 0.12 | 0.86 | 0.014 |
| 6 | Volcanic ash | Lock site.. | 40 | 0.21 | 1.50 | 0.024 |
| 7 | Light blue-gray conglomerate | Lock site.. | 40 | 0.28 | 2.0 | 0.032 |
| 8 | Argillaceous sandstone | Spillway... | 40 | 0.40 | 2.9 | 0.047 |
| 9 | Gray sandstone | Spillway... | 40 | 0.26 | 1.9 | 0.030 |
| 10 | Light brown sandstone | Spillway... | 40 | 0.71 | 5.1 | 0.082 |

Although these figures exceed considerably those found for the soils, no effort will be made to carry the calculation further, as it is obvious that the rates of seepage indicated are too small to be of practical significance.

The materials on the Isthmus, as the writer saw them in February, 1909, are generally of a ferruginous, clayey nature. That is, they are clays and shales, part of the alumina in which has been replaced with iron to the extent that they contain something like 10% of metallic iron. The substitution of iron for alumina changes the physical

properties of the materials to such an extent that Northern experience cannot be applied safely, and their ability to stand up in stable embankments must be based on actual experience with them rather than on considerations of Northern precedent. Mr. Hazen.

In the whole line of the work traversed by the Canal there is no considerable deposit of silicious sand or gravel. The so-called sandstone does not contain silicious sand particles, but, in appearance and in physical properties, is more like shale than the rock which we know as sandstone. This so-called sandstone, said to be water-bearing, does not permit percolation through its pores. There are occasional seams in it which carry limited quantities of water, in the same way that shales and mica schists and granites are fissured, and carry water in limited quantities.

All these materials, as seen by the writer in the various cuts on the work, and as tested by Mr. Saville in his laboratory, are substantially impervious.

Of course, it is true that the engineers did not have an opportunity to see every part of the lake bottom. That would have been impossible under existing conditions, and especially in a limited time, but the materials which they did see extending from one end of the lake to the other, and, in many places to its sides, were all of the same general class, and were all generally impervious, and there is every reason to believe that the materials throughout the whole lake are of the same general character.

There is no more reason to apprehend loss of water from Gatun Lake by percolation than there is to expect loss in the Ashokan Reservoir now building by the City of New York. No allowance for such percolation has been made for the Ashokan Reservoir, as experience with the Croton Reservoir, the Wachusett Reservoir, and a hundred smaller reservoirs, has not indicated the necessity for it.

The author speaks of some of the dams built for water-works' purposes on the Isthmus, and of the leakage from them. The writer visited several and noted the conditions of leakage. These dams were made by filling with the materials most conveniently available to a not very large earth dam section, and apparently without any very deep preparatory excavation of the underlying material. In all cases there was a certain amount of seepage at the bases of the dams, coming apparently through the material under the dam a short distance below the natural surface. In one case a slight indication of leakage through the lower part of the embankment was observed. In no case was there indication of leakage through the deeper underlying materials.

The writer is at a loss to account for this percolation through the material a short distance below the natural surface. His first thought was that it might be due to the spaces left by decayed roots, but observation in cuts showed that as a rule roots did not extend far into the

Mr. Hazen. soil, and the seepage was through a layer deeper than that to which roots ordinarily extend. The writer has been told that in very dry seasons there are shrinkage cracks, due to the continued extraction of moisture, by roots and otherwise by evaporation, from the clayey soil containing a large percentage of pores filled by moisture, and that these shrinkage cracks sometimes extend to considerable depths. It may be that these cracks when once formed do not completely heal in the ensuing rainy season, and that there may be seepage through them.

The seepage from these reservoirs used for water-supply purposes in no case seems to be enough to affect the stability of the dams, nor to take away to any considerable extent from the quantity of water available for water-supply purposes.

The writer is interested to note that Mr. Sorzano raises no question as to the loss of water by seepage through the Gatun Dam itself, and he believes that all parts of Gatun Lake formed by it will be equally tight.

Mr. Saville, C. M. SAVILLE, M. AM. SOC. C. E. (by letter).—Mr. Sorzano has brought together many interesting features pertaining to the lock canal at Panama and its operation, and, on account of the magnitude of the work, its commercial future, and its engineering problems, everything bearing thereon is of interest for study and discussion. It is to be regretted, however, that the author had not at hand more complete data on which to base some of his premises. The conditions of meteorology, geology, and hydrography on the Isthmus differ so radically from those elsewhere observed, and especially in the United States, that knowledge gained solely from experience there would almost inevitably lead astray in the interpretation of Isthmian records, and particularly is this the case if those records happen to be incomplete. Under ordinary conditions, a section of country 50 miles long might be expected to present no radical differences in rainfall, but the annual precipitation at Ancon, on the Pacific side, varies from 60 to 80 in., while at Cristobal, on the Atlantic side, the range is from 125 to 140 in. In Table 10, "Rainfall on the Isthmus of Panama," are given the records as they are available at the present time, and Figs. 2 and 3 are diagrams showing the distribution of the rainfall. The upper curves show the average annual rainfall for the years of record, and the yearly rainfall for 1907 and 1908. The lower curves show the average annual amount for the 4 months of minimum precipitation, and the amount for this period in 1908.

Fig. 4 is a sketch map showing the Chagres River drainage basin, the extent of the proposed Gatun Lake, and the relative locations of the several meteorological and hydrographic stations. In the present discussion, the area of the entire Chagres drainage basin above Gatun is taken as 1 320 sq. miles. Subdividing this at the several gauging stations shown on the map gives the figures in Table 11.

Mr. Saville.

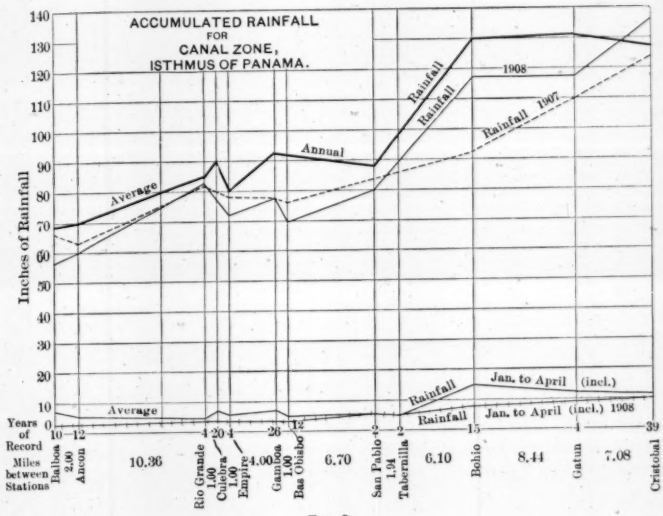



FIG. 2.

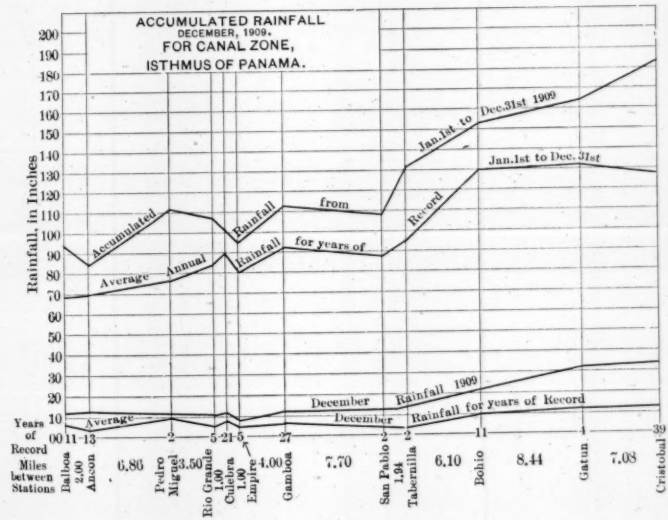



FIG. 3.

Mr. Saville.

TABLE 10.—RAINFALL JANUARY 1ST, 1909,

| Station. | Station Average. No. of Years. | | January. Current month. | January. Accumulated. | February. Current month. | February. Accumulated. | March. Current month. | March. Accumulated. | April. Current month. | April. Accumulated. |
|---|---|---|---|---|---|---|---|---|---|---|
| Balboa | 12 | 1908 | 0.21 | 0.21 | 0.55 | 0.76 | Tr. | 0.76 | 0.76 | 1.52 |
| | | 1909 | 1.45 | 1.45 | 1.69 | 3.14 | 0.14 | 3.28 | 2.83 | 6.11 |
| | | Average. | 1.30 | 1.30 | 0.21 | 1.51 | 0.95 | 2.46 | 4.06 | 6.52 |
| Ancon | 11 | 1908 | 0.12 | 0.12 | 0.24 | 0.36 | 0.03 | 0.39 | 1.37 | 1.76 |
| | | 1909 | 2.90 | 2.90 | 2.90 | 5.80 | 0.18 | 5.98 | 2.92 | 8.90 |
| | | Average. | 0.93 | 0.93 | 0.58 | 1.51 | 0.87 | 2.38 | 2.30 | 4.68 |
| Pedro Miguel | 1 | 1908 | 0.01 | 0.01 | 0 | 0.01 | 0.10 | 0.11 | 1.17 | 1.28 |
| | | 1909 | 3.08 | 3.08 | 3.26 | 6.34 | 0.59 | 6.93 | 2.32 | 9.25 |
| | | Average. | 0.01 | 0.01 | 0 | 0.01 | 0.10 | 0.11 | 1.17 | 1.28 |
| Rio Grande | 4 | 1908 | 0.75 | 0.75 | 0 | 0.75 | 0.14 | 0.89 | 2.00 | 2.89 |
| | | 1909 | 3.85 | 3.85 | 2.88 | 6.73 | 0.18 | 6.91 | 2.63 | 9.54 |
| | | Average. | 1.30 | 1.30 | 0.07 | 1.37 | 0.16 | 1.53 | 2.58 | 4.11 |
| Culebra | 17 | 1908 | 0.91 | 0.91 | 0.01 | 0.92 | 0.13 | 1.05 | 1.67 | 2.72 |
| | | 1909 | 2.96 | 2.96 | 2.46 | 5.42 | 0.15 | 5.57 | 2.56 | 8.13 |
| | | Average. | 1.89 | 1.89 | 0.43 | 2.32 | 0.75 | 3.07 | 3.76 | 6.83 |
| Camacho | 2 | 1908 | 1.70 | 1.70 | 0.01 | 1.71 | 0.38 | 2.09 | 1.90 | 3.99 |
| | | 1909 | 3.29 | 3.29 | 2.16 | 5.45 | 0.40 | 5.85 | 2.64 | 8.49 |
| | | Average. | 0.90 | 0.90 | Tr. | 0.90 | 0.26 | 1.16 | 1.07 | 2.23 |
| Empire | 5 | 1908 | 0.75 | 0.75 | 0 | 0.75 | 0.41 | 1.16 | 1.36 | 2.52 |
| | | 1909 | 2.28 | 2.28 | 1.50 | 3.78 | 0.21 | 3.99 | 3.33 | 7.32 |
| | | Average. | 0.70 | 0.70 | 0.23 | 0.93 | 0.34 | 1 27 | 3.58 | 4.85 |
| Gamboa | 27 | 1908 | 0.19 | 0.19 | 0.04 | 0.23 | 0.50 | 0.73 | 2.65 | 3.38 |
| | | 1909 | 2.77 | 2.77 | 4.07 | 6.84 | 0.56 | 7.40 | 5.55 | 12.95 |
| | | Average. | 1.98 | 1.98 | 0.67 | 2.65 | 0.80 | 3.45 | 3.54 | 6.99 |
| San Pablo | 2 | 1908 | 0.80 | 0.80 | 0.09 | 0.89 | 0.49 | 1.38 | 3.39 | 4.77 |
| | | 1909 | 4.09 | 4.09 | 1.76 | 5.85 | 0.46 | 6.31 | 5.50 | 11.81 |
| | | Average. | 0.80 | 0.80 | 0.09 | 0.89 | 0.49 | 1.38 | 3.39 | 4.77 |
| Tabernilla | 2 | 1908 | 0.92 | 0.92 | 0.35 | 1.27 | 0.73 | 2.00 | 2.37 | 4.37 |
| | | 1909 | 4.58 | 4.58 | 2.87 | 7.45 | 0.99 | 8.44 | 6.30 | 14.74 |
| | | Average. | 0.92 | 0.92 | 0.35 | 1.27 | 0.73 | 2.00 | 2.37 | 4.37 |
| Bohio | 14 | 1908 | 1.59 | 1.59 | 1.17 | 2.76 | 1.77 | 4.53 | 2.16 | 6.69 |
| | | 1909 | 7.29 | 7.29 | 3.74 | 11.03 | 3.66 | 14.69 | 7.23 | 21.92 |
| | | Average. | 6.49 | 6.49 | 1.64 | 8.13 | 1.61 | 9.74 | 5.70 | 15.44 |
| Trinidad | 1 | 1908 | 2.72 | 2.72 | 0.87 | 3.59 | 1.97 | 5.56 | 3.40 | 8.96 |
| | | 1909 | 7.58 | 7.58 | 4.27 | 11.85 | 3.08 | 14.93 | 6.96 | 21.89 |
| | | Average. | 2.72 | 2.72 | 0.87 | 3.59 | 1.97 | 5.56 | 3.40 | 8.96 |
| *Monte Lirio | 1 | 1908 | 2.79 | 2.79 | 1.38 | 4.17 | 2.72 | 6.89 | 3.63 | 10.52 |
| | | 1909 | 7.94 | 7.94 | 5.69 | 13.63 | 4.85 | 18.48 | 7.18 | 25.66 |
| | | Average. | 2.79 | 2.79 | 1.38 | 4.17 | 2.72 | 6.89 | 3.63 | 10.52 |
| Gatun | 3 | 1908 | 3.18 | 3.18 | 1.29 | 4.47 | 2.81 | 7.28 | 1.47 | 8.75 |
| | | 1909 | 7.17 | 7.17 | 4.12 | 11.29 | 2.99 | 14.28 | 4.03 | 18.31 |
| | | Average. | 4.13 | 4.13 | 1.80 | 5.93 | 2.22 | 8.15 | 3.22 | 11.37 |
| Brazos Brook | 2 | 1908 | 4.30 | 4.30 | 1.17 | 5.47 | 3.01 | 8.48 | 1.33 | 9.81 |
| | | 1909 | 9.10 | 9.10 | 4.13 | 13.23 | 2.90 | 16.13 | 6.23 | 22.36 |
| | | Average. | 3.18 | 3.18 | 1.04 | 4.22 | 2.49 | 6.71 | 1.20 | 7.91 |
| Cristobal | 38 | 1908 | 3.84 | 3.84 | 1.08 | 4.92 | 3.53 | 8.45 | 1.27 | 9.72 |
| | | 1909 | 10.61 | 10.61 | 1.92 | 12.53 | 1.85 | 14.38 | 3.56 | 17.94 |
| | | Average. | 3.99 | 3.99 | 1.39 | 5.38 | 1.60 | 6.98 | 4.23 | 11.21 |
| Porto Bello | .. | 1908 | .... | .... | .... | .... | .... | .... | .... | .... |
| | | 1909 | 20.90 | 20.90 | 6.82 | 27.72 | 3.56 | 31.28 | 12.56 | 43.84 |
| Nombre de Dios | 0 | 1909 | 15.26 | 15.26 | 8.64 | 23.90 | 1.43 | 25.33 | 12.58 | 37.91 |
| El Vigia | 0 | 1908 | .... | .... | .... | .... | .... | .... | .... | .... |
| | | 1909 | 3.91 | 3.91 | 4.88 | 8.79 | 0.32 | 9.11 | 2.32 | 11.43 |
| Alhajuela | 9 | 1908 | 1.02 | 1.02 | 0.18 | 1.20 | 0.24 | 1.44 | 4.61 | 6.05 |
| | | 1909 | 2.72 | 2.72 | 3.71 | 6.43 | 0.29 | 6.72 | 3.54 | 10.26 |
| | | Average. | 1.12 | 1.12 | 0.15 | 1.27 | 0.61 | 1.88 | 3.36 | 5.24 |

* Formerly designated as "Gatuncillo" and "Gatun River."
† No record after December 26th; gauge washed out.
NOTE.—"Years of Record" and "Averages" are exclusive of 1909.

ON THE ISTHMUS OF PANAMA.
TO DECEMBER 31ST, 1909.

Mr. Saville.

| MAY. | | JUNE. | | JULY. | | AUGUST. | | SEPTEMBER. | | OCTOBER. | | NOVEMBER. | | DECEMBER. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Current month. | Accumulated. | Current month. | Accumulated. | Current month. | Accumulated. | Current month. | Accumulated. | Current month. | Accumulated. | Current month. | Accumulated. | Current month. | Accumulated. | Current month. | Accumulated. |
| 8.65 | 10.17 | 4.98 | 15.15 | 5.66 | 20.81 | 10.48 | 31.29 | 5.93 | 37.22 | 7.51 | 44.73 | 7.37 | 52.10 | 4.61 | 56.71 |
| 9.69 | 15.80 | 12.06 | 27.86 | 14.92 | 42.78 | 6.86 | 49.64 | 4.11 | 53.75 | 11.20 | 64.95 | 15.99 | 80.94 | 12.12 | 93.06 |
| 6.54 | 13.06 | 7.88 | 20.94 | 9.75 | 30.69 | 7.27 | 37.96 | 6.71 | 44.67 | 8.83 | 53.50 | 9.56 | 63.06 | 5.54 | 68.60 |
| 7.64 | 9.40 | 4.28 | 13.68 | 6.83 | 20.51 | 11.48 | 31.99 | 5.93 | 37.92 | 8.79 | 46.71 | 9.12 | 55.83 | 4.16 | 59.99 |
| 9.10 | 18.00 | 9.90 | 27.90 | 9.01 | 36.91 | 6.84 | 43.75 | 3.86 | 47.61 | 8.77 | 56.38 | 15.14 | 71.52 | 12.39 | 83.91 |
| 8.50 | 13.18 | 8.57 | 21.75 | 8.02 | 29.77 | 7.34 | 37.11 | 8.02 | 45.13 | 10.70 | 55.83 | 11.15 | 66.98 | 3.21 | 70.19 |
| 4.73 | 16.01 | 7.71 | 23.72 | 9.53 | 33.25 | 9.31 | 42.56 | 7.56 | 50.12 | 8.41 | 58.53 | 8.65 | 67.18 | 10.27 | 77.45 |
| 8.50 | 17.75 | 14.19 | 31.94 | 9.19 | 41.13 | 10.07 | 51.20 | 10.22 | 61.42 | 17.47 | 78.89 | 20.38 | 99.27 | 11.30 | 110.57 |
| 4.73 | 16.01 | 7.71 | 23.72 | 9.53 | 33.25 | 9.31 | 42.56 | 7.56 | 50.12 | 8.41 | 58.53 | 8.65 | 67.18 | 10.27 | 77.45 |
| 4.26 | 17.15 | 11.08 | 28.23 | 12.55 | 40.78 | 7.65 | 48.43 | 15.32 | 63.75 | 8.59 | 72.34 | 5.30 | 77.64 | 5.53 | 83.17 |
| 7.32 | 16.86 | 9.27 | 26.13 | 8.13 | 34.26 | 9.12 | 43.38 | 11.23 | 54.61 | 18.52 | 73.13 | 24.17 | 97.30 | 10.56 | 107.86 |
| 11.24 | 15.35 | 10.78 | 26.13 | 12.07 | 38.20 | 10.83 | 49.03 | 11.58 | 60.61 | 11.58 | 71.99 | 8.24 | 80.23 | 5.17 | 85.40 |
| 12.63 | 15.35 | 8.86 | 24.21 | 13.23 | 37.44 | 7.74 | 45.18 | 13.74 | 58.92 | 9.03 | 67.95 | 5.10 | 73.05 | 4.40 | 77.45 |
| 7.36 | 15.49 | 9.44 | 24.93 | 7.95 | 32.88 | 8.32 | 41.20 | 8.40 | 49.60 | 17.70 | 67.30 | 24.46 | 91.76 | 10.58 | 102.34 |
| 11.37 | 18.20 | 9.03 | 27.23 | 9.39 | 36.62 | 10.73 | 47.35 | 11.58 | 58.93 | 10.93 | 69.86 | 12.00 | 81.86 | 7.85 | 89.71 |
| 17.29 | 21.28 | 12.87 | 34.15 | 12.83 | 46.98 | 8.28 | 55.26 | 12.35 | 67.61 | 6.81 | 74.42 | 6.65 | 81.07 | 7.80 | 88.87 |
| 9.34 | 17.83 | 10.52 | 28.35 | 8.68 | 37.03 | 8.03 | 45.06 | 13.01 | 58.07 | 20.63 | 78.70 | 27.07 | 105.77 | 10.54 | 116.31 |
| 11.34 | 13.57 | 12.83 | 26.40 | 11.44 | 37.84 | 10.82 | 48.66 | 10.64 | 59.30 | 10.25 | 69.55 | 11.10 | 80.65 | 6.50 | 87.15 |
| 12.91 | 15.43 | 8.21 | 23.64 | 11.79 | 35.43 | 8.11 | 43.54 | 9.76 | 53.30 | 8.87 | 62.17 | 4.46 | 66.63 | 5.09 | 71.72 |
| 7.73 | 15.05 | 7.84 | 22.89 | 8.37 | 31.16 | 7.20 | 38.36 | 7.22 | 45.58 | 21.14 | 66.72 | 30.99 | 87.71 | 9.44 | 97.15 |
| 9.58 | 14.43 | 8.40 | 22.83 | 10.14 | 32.97 | 10.74 | 43.71 | 7.87 | 51.58 | 12.82 | 64.40 | 9.77 | 74.17 | 5.55 | 79.72 |
| 15.29 | 18.67 | 6.15 | 24.82 | 11.43 | 36.25 | 11.84 | 48.09 | 6.28 | 54.37 | 8.90 | 63.27 | 7.32 | 70.59 | 6.92 | 77.51 |
| 15.37 | 28.32 | 9.55 | 37.87 | 11.59 | 49.46 | 7.03 | 56.49 | 7.90 | 64.39 | 16.98 | 81.37 | 28.41 | 109.78 | 12.33 | 122.11 |
| 10.72 | 17.71 | 9.64 | 27.35 | 10.14 | 37.49 | 12.46 | 49.95 | 10.65 | 60.60 | 12.60 | 73.20 | 11.76 | 84.96 | 6.89 | 91.85 |
| 11.34 | 16.11 | 9.95 | 26.06 | 7.59 | 33.65 | 10.70 | 44.35 | 9.42 | 53.77 | 12.95 | 66.72 | 8.90 | 75.62 | 4.12 | 79.74 |
| 9.00 | 20.81 | 10.80 | 31.61 | 10.63 | 42.24 | 9.04 | 51.28 | 12.17 | 63.45 | 15.81 | 79.26 | 27.59 | 106.85 | 12.10 | 118.95 |
| 11.34 | 16.11 | 10.75 | 26.86 | 9.96 | 36.82 | 10.84 | 47.66 | 11.40 | 59.06 | 15.94 | 75.00 | 9.92 | 84.92 | 3.89 | 88.81 |
| 14.79 | 19.16 | 10.41 | 29.57 | 7.84 | 37.41 | 11.02 | 48.43 | 12.85 | 61.28 | 14.57 | 75.85 | 10.85 | 86.70 | 3.25 | 89.95 |
| 10.07 | 24.81 | 11.16 | 35.97 | 10.78 | 46.75 | 9.78 | 56.53 | 13.10 | 69.63 | 17.02 | 86.65 | 30.84 | 117.49 | 13.59 | 131.08 |
| 14.79 | 19.16 | 10.41 | 29.57 | 7.76 | 37.33 | 11.18 | 48.51 | 12.68 | 61.19 | 20.52 | 81.71 | 10.82 | 92.53 | 4.04 | 96.57 |
| 18.59 | 25.28 | 20.02 | 45.30 | 7.78 | 53.08 | 20.50 | 73.58 | 8.74 | 82.32 | 14.25 | 96.57 | 19.01 | 115.58 | 3.40 | 118.98 |
| 13.69 | 35.61 | 12.31 | 47.92 | 11.07 | 58.99 | 10.01 | 69.00 | 10.43 | 79.43 | 16.34 | 95.77 | 35.39 | 131.16 | 20.53 | 151.69 |
| 13.93 | 29.37 | 12.52 | 41.89 | 13.00 | 54.89 | 15.76 | 70.65 | 14.07 | 84.72 | 16.98 | 101.70 | 18.13 | 119.83 | 9.87 | 129.70 |
| 18.41 | 27.37 | 8.86 | 36.23 | 6.46 | 42.69 | 19.00 | 61.69 | 12.79 | 74.48 | 12.59 | 87.07 | 14.19 | 101.26 | 7.23 | 108.49 |
| 10.79 | 32.68 | 14.86 | 47.54 | 10.78 | 58.32 | 9.50 | 67.82 | 13.64 | 81.46 | 14.58 | 96.04 | 33.28 | 129.32 | 18.49 | 147.81 |
| 18.41 | 27.37 | 8.86 | 36.23 | 6.46 | 42.69 | 19.00 | 61.69 | 12.79 | 74.48 | 12.59 | 87.07 | 14.19 | 101.26 | 5.06 | 106.32 |
| 22.54 | 33.06 | 14.48 | 47.54 | 12.98 | 60.52 | 15.88 | 76.40 | 7.88 | 84.28 | 13.53 | 97.81 | 25.57 | 123.38 | 6.34 | 129.72 |
| 9.29 | 34.95 | 12.36 | 47.31 | 15.63 | 62.94 | 8.39 | 71.33 | 9.87 | 81.20 | 13.38 | 94.58 | 34.73 | 129.31 | 24.08 | 153.39 |
| 22.54 | 33.06 | 14.48 | 47.54 | 12.98 | 60.52 | 15.88 | 76.40 | 7.88 | 84.28 | 13.53 | 97.81 | 25.57 | 123.38 | 5.47 | 128.85 |
| 17.30 | 26.05 | 13.33 | 39.38 | 13.67 | 53.05 | 16.22 | 69.27 | 8.52 | 77.79 | 12.22 | 90.01 | 21.37 | 111.38 | 7.95 | 119.33 |
| 8.98 | 27.29 | 16.35 | 43.64 | 11.46 | 55.10 | 9.92 | 65.02 | 10.86 | 75.88 | 15.55 | 91.43 | 41.10 | 132.53 | 31.66 | 164.19 |
| 16.92 | 28.29 | 13.05 | 41.34 | 12.63 | 53.97 | 18.90 | 72.87 | 10.48 | 83.35 | 17.48 | 100.83 | 19.26 | 120.09 | 11.02 | 131.11 |
| 22.10 | 31.91 | 14.81 | 46.72 | 18.25 | 64.97 | 18.19 | 83.16 | 12.05 | 95.21 | 11.95 | 107.16 | 27.12 | 134.28 | 9.48 | 143.76 |
| 7.51 | 29.87 | 18.63 | 48.50 | 12.23 | 60.73 | 10.67 | 71.40 | 9.66 | 81.06 | 14.82 | 95.88 | 38.17 | 134.05 | 36.45 | 170.50 |
| 14.46 | 22.37 | 14.81 | 37.18 | 17.68 | 54.86 | 17.32 | 72.18 | 13.23 | 85.41 | 15.59 | 101.00 | 21.56 | 122.56 | 10.41 | 132.97 |
| 22.49 | 32.21 | 10.53 | 42.74 | 14.76 | 57.50 | 16.89 | 74.39 | 11.57 | 85.96 | 10.96 | 96.92 | 31.72 | 128.64 | 9.07 | 137.71 |
| 7.21 | 25.15 | 17.49 | 42.64 | 12.83 | 55.47 | 15.42 | 70.89 | 16.33 | 87.22 | 19.31 | 106.53 | 42.50 | 149.03 | 34.38 | 183.41 |
| 12.45 | 28.66 | 13.11 | 36.77 | 16.48 | 53.25 | 15.22 | 68.47 | 12.48 | 80.95 | 13.98 | 94.93 | 21.26 | 116.19 | 11.93 | 128.12 |
| 21.08 | ..... | 16.99 | ..... | 9.98 | ..... | 16.98 | ..... | 8.59 | ..... | 7.28 | ..... | 41.73 | ..... | 25.72 | ..... |
| 9.69 | 53.53 | 17.70 | 71.23 | 26.33 | 97.56 | 13.83 | 111.39 | 13.99 | 125.38 | 8.70 | 134.08 | 45.08 | 179.11 | 58.17 | 237.28 |
| 8.11 | 46.02 | 18.02 | 64.04 | 16.94 | 80.98 | 12.15 | 93.13 | 7.72 | 100.85 | 18.17 | 119.02 | 25.62 | 144.64 | 36.04 | 180.68 |
| ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 17.39 | ..... | 13.80 | ..... | 12.07 | ..... | 3.69 | ..... |
| 15.54 | 26.97 | 16.93 | 43.90 | 14.09 | 57.99 | 11.24 | 69.23 | 10.91 | 80.14 | 20.93 | 101.07 | 35.64 | 136.71 | 10.90 | 147.61† |
| 19.72 | 25.77 | 11.06 | 36.83 | 9.68 | 46.51 | 16.64 | 63.15 | 13.45 | 76.60 | 15.09 | 91.69 | 10.55 | 102.24 | 4.02 | 106.26 |
| 14.92 | 24.58 | 19.73 | 44.31 | 13.64 | 57.95 | 8.15 | 66.10 | 7.50 | 73.60 | 19.32 | 92.92 | 36.22 | 129.14 | 22.90 | 152.04 |
| 12.21 | 17.45 | 12.34 | 29.79 | 13.56 | 43.35 | 13.79 | 57.14 | 11.80 | 68.94 | 12.77 | 81.71 | 12.53 | 94.24 | 5.81 | 100.05 |

Mr. Saville.

TABLE 11.—Areas and Discharge, Gatun Basin and Lake.

| | Area of entire drainage basin, in square miles. | Approximate area flooded by proposed lake. El. 87. | Approximate division of the flow at Gatun. Percentage. |
|---|---|---|---|
| 1—Above Alhajuela | 427 | .... | 45 |
| 2—Between Bohio and Alhajuela | 352 | 42 | 20 |
| 3—Above Gatun River | 127 | 11 | 6 |
| 4—Above Lagartera (Trinidad River) | 314 | 53 | 19 |
| 5—Remaining area above Gatun | 100 | 61 | 10 |
| 6—Total area above Gatun | 1 320 | 167 | 100 |

Unlike many tropical countries, the Isthmus of Panama does not have well-defined wet and dry periods, and in certain sections the seasonal differences have been feelingly referred to by surveyors as "the wet and the d——d wet." In Table 12 the records are arranged in periods of minimum rainfall available for those stations which best represent conditions that may be expected on the area to be covered by Gatun Lake. An examination of this table will disclose the fact that the stations noted in Table 1 (designated by the author "Rainfall in the Canal Zone, for the Year 1908, in Inches") are in the central part of the Isthmus, and, with one exception, are comparatively remote from the lake. Culebra is on the continental divide, and Rio Grande is outside the Chagres River drainage area, its water flowing southeastward into the Pacific Ocean. Chagres is the Bas Obispo station, which is now abandoned on account of its location on a hilltop, where the general meteorological conditions of this locality were not properly represented. From Table 10 it can be seen that the rainfall is very much less in this interior section than at other places in the Chagres Basin. Study of the topography would lead to this expectation. Rain clouds coming in from the Caribbean Sea first meet the cooler land at Cristobal, and a portion of their burden is precipitated there. Driving south along the depressions of the Chagres and Mindi Rivers, the clouds are deflected upward into the cooler currents by the hills at the narrow gorge at Gatun, and again precipitation results. Continuing southward, they strike the highlands west of Bohio, and once more the conditions of rainfall are established. The rain clouds now are greatly depleted, and, being divided, part go southward up the Trinidad Valley, part northward up the Gatun River, and part eastward up the main Chagres Valley. This portion again is divided by the hills at Bas Obispo, and some part continues up the river toward Alhajuela and the remainder goes eastward to strike the continental divide at Culebra. A reason thus appears for the smaller rainfall in the section covered by the records given in Table 1, and it is believed that this table does not give a true idea of the variations in "the only

Mr. Saville.

## TABLE 12.—Periods of Minimum Rainfall.

(Consecutive Periods—Calendar Months.)

| Period. | Cristobal. | | | Bohio. | | | Gamboa. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Amount, in inches. | Date (including). | | Amount, in inches. | Date (including). | | Amount, in inches. | Date (including). | |
| 1 month | 0.04 | Feb. 1897 | ..... | 0.00 | Feb. 1897 | ..... | 0.00 | Feb. 1891; Mar. 1897; Mar. 1898 | |
| 2 months | 0.32 | " 1907 | Mar. 1907 | 0.25 | " " | Mar. 1897 | 0.12 | Feb. 1898 | Mar. 1898 |
| 3 " | 2.14 | " 1900 | Apr. 1900 | 2.14 | " 1905 | Apr. 1905 | 0.73 | Jan. 1908 | " 1908 |
| 4 " | 4.00 | Jan. 1903 | " 1903 | 5.13 | Jan. 1907 | " 1907 | 1.36 | " 1907 | Apr. 1907 |
| 5 " | 9.52 | Dec. 1900 | " 1901 | 9.57 | Dec. " | " 1908 | 2.37 | Dec. 1900 | " 1901 |
| 6 " | 15.71 | " " | May 1901 | 20.95 | Nov. " | " " | 13.24 | " " | May " |
| 7 " | 26.76 | " " | June " | 31.35 | Dec. 1902 | June 1903 | 20.92 | " " | June " |
| 8 " | 36.70 | " " | July " | 42.05 | " " | July " | 29.23 | Nov. 1897 | " 1898 |
| 9 " | 49.21 | " " | Aug. " | 53.09 | " " | Aug. " | 38.73 | Dec. 1890 | Aug. 1891 |
| 10 " | 61.09 | " " | Sept. " | 66.16 | Nov. " | " " | 48.65 | Nov. " | " " |
| 11 " | 73.74 | " " | Oct. " | 77.44 | June 1904 | Apr. 1905 | 59.12 | " " | Sept. " |
| 1 year | 94.02 | Nov. " | " " | 89.68 | May " | " " | 73.55 | Dec. 1907 | Nov. 1908 |
| 2 years | 216.63 | Dec. " | Nov. 1902 | 191.36 | June " | May 1906 | 150.69 | May 1899 | Apr. 1901 |
| 3 " | 330.46 | Apr. " | Mar. 1903 | 297.72 | " " | " 1907 | 238.51 | " 1898 | " " |
| 4 " | 441.38 | Nov. 1899 | Oct. " | 396.50 | May " | Apr. 1908 | 320.63 | Oct. 1897 | Sept. " |
| 5 " | 575.37 | May 1898 | Apr. " | 520.76 | June 1902 | May 1907 | 418.44 | Feb. 1904 | Jan. 1909 |
| 6 " | 707.37 | Aug. " | July 1904 | 621.20 | May " | Apr. 1908 | 513.81 | Dec. 1902 | Nov. 1908 |
| 7 " | 828.44 | " " | " 1905 | 747.81 | Feb. " | Jan. 1909 | 605.62 | Feb. " | Jan. 1909 |
| 8 " | 942.91 | " " | " 1906 | 934.23 | Jan. 1901 | Dec. 1908 | 697.28 | " 1898 | " 1906 |
| 9 " | 1 081.81 | July 1897 | June " | 1 052.76 | Apr. 1899 | Mar. " | 780.87 | Nov. 1897 | Oct. " |
| 10 " | 1 209.03 | June 1896 | May " | 1 181.52 | Mar. " | Feb. 1909 | 861.92 | Dec. 1898 | Nov. 1908 |
| 11 " | 1 342.15 | " " | " 1907 | 1 383.89 | Feb. 1898 | Jan. " | 949.07 | Jan. " | Dec. " |
| 12 " | 1 480.41 | May " | Apr. 1908 | 1 558.70 | Jan. 1897 | Dec. 1908 | 1 056.10 | " 1897 | " " |
| 13 " | 1 620.13 | Nov. 1895 | Oct. " | | | | | | |
| 14 " | 1 776.24 | Jan. " | Dec. " | | | | | | |
| 15 " | 1 924.13 | " 1893 | " 1907 | | | | | | |
| 16 " | 2 058.16 | Aug. 1892 | July 1908 | | | | | | |
| 17 " | 2 200.87 | July 1891 | June " | | | | | | |
| 18 " | 2 331.84 | Jan. " | Dec. " | | | | | | |
| 19 " | 2 444.90 | May 1890 | June " | | | | | | |

Mr. Saville.

source of water supply" in that locality. The rainfall at these stations, therefore, is not representative of that which will probably obtain on Gatun Lake. The average annual rainfall on the section west of Bohio is about 50% greater than that in the region covered by Table 1, and the average dry-season precipitation of the former exceeds the latter nearly 2.6 times. To realize adequately the bearing of this condition, it must be remembered that nearly three-quarters of the total

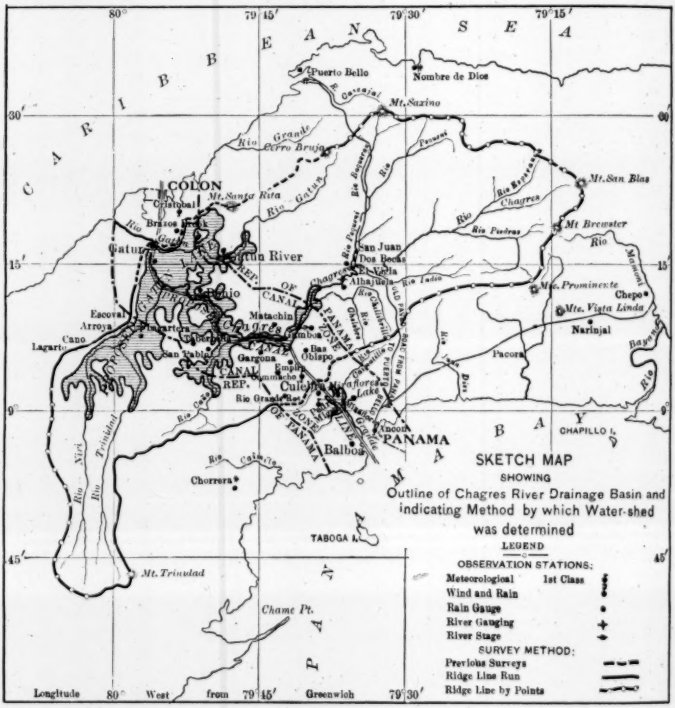



FIG. 4.

lake area is in the region exposed to the heavy precipitation of Gatun and Bohio. The foregoing is given for information bearing on the depletion of the lake from evaporation.

Regarding the rainfall in the entire basin, the run-off records contain the best and most useful data. It will suffice to say that it is generally recognized that heavy precipitation conditions, similar to those of the Caribbean Coast, prevail in all parts of the basin except in the small portion nearly included between Bas Obispo, Culebra, and Alhajuela.

TABLE 13.—RAINFALL CONDITIONS APPLICABLE TO THE LARGER PART OF GATUN LAKE. Mr. Saville.

| STATION. | GATUN. | | TRINIDAD. | | GATUN RIVER. | | BOHIO. | | Means, in inches. |
|---|---|---|---|---|---|---|---|---|---|
| Years of record. | 4 Years. | | 1½ Years. | | 1½ Years. | | 15 Years. | | |
| Season. | Dry. | Wet. | Dry. | Wet. | Dry. | Wet. | Dry. | Wet. | |
| Rainfall. | Inches. | | Inches. | | Inches. | | Inches. | | |
| 1907-1908. | | | | | | | | | |
| July | ..... | 11.12 | ..... | ..... | ..... | ..... | ..... | 8.70 | 9.91 |
| August | ..... | 16.37 | ..... | ..... | ..... | ..... | ..... | 9.10 | 12.74 |
| September | ..... | 8.08 | ..... | ..... | ..... | ..... | ..... | 13.63 | 10.83 |
| October | ..... | 19.27 | ..... | ..... | ..... | ..... | ..... | 19.00 | 19.14 |
| November | ..... | 14.27 | ..... | ..... | ..... | ..... | ..... | 11.38 | 12.83 |
| December | ..... | 5.53 | ..... | ..... | ..... | ..... | ..... | 2.88 | 4.20 |
| January | 3.18 | ..... | 2.72 | ..... | 2.79 | ..... | 1.59 | ..... | 2.57 |
| February | 1.29 | ..... | 0.87 | ..... | 1.38 | ..... | 1.17 | ..... | 1.18 |
| March | 2.81 | ..... | 1.97 | ..... | 2.72 | ..... | 2.76 | ..... | 2.56 |
| April | 1.47 | ..... | 3.40 | ..... | 3.63 | ..... | 2.16 | ..... | 2.66 |
| May | ..... | 17.30 | ..... | 18.41 | ..... | 22.54 | ..... | 18.59 | 19.21 |
| June | ..... | 13.33 | ..... | 8.86 | ..... | 14.48 | ..... | 20.02 | 14.17 |
| Totals | 8.75 | 105.22 | 8.96 | 27.27 | 10.52 | 37.02 | 7.68 | 103.30 | 112.00 |
| 1908-1909. | | | | | | | | | |
| July | ..... | 13.67 | ..... | 6.46 | ..... | 12.98 | ..... | 7.78 | 10.22 |
| August | ..... | 16.22 | ..... | 19.00 | ..... | 15.88 | ..... | 20.50 | 17.90 |
| September | ..... | 8.52 | ..... | 12.79 | ..... | 7.88 | ..... | 8.74 | 9.48 |
| October | ..... | 12.22 | ..... | 12.59 | ..... | 13.53 | ..... | 14.25 | 13.15 |
| November | ..... | 21.37 | ..... | 14.19 | ..... | 25.57 | ..... | 19.01 | 20.04 |
| December | ..... | 7.95 | ..... | 7.23 | ..... | 6.34 | ..... | 3.40 | 6.23 |
| January | 7.17 | ..... | 7.58 | ..... | 7.94 | ..... | 7.29 | ..... | 7.50 |
| February | 4.12 | ..... | 4.27 | ..... | 5.69 | ..... | 3.74 | ..... | 4.46 |
| March | 2.99 | ..... | 3.08 | ..... | 4.85 | ..... | 3.66 | ..... | 3.64 |
| April | 4.03 | ..... | 6.96 | ..... | 7.18 | ..... | 7.23 | ..... | 6.35 |
| May | ..... | 8.98 | ..... | 10.79 | ..... | 9.29 | ..... | 13.69 | 10.69 |
| June | ..... | 16.35 | ..... | 14.86 | ..... | 12.36 | ..... | 12.31 | 13.97 |
| Totals | 18.31 | 105.28 | 21.89 | 97.91 | 25.66 | 103.83 | 21.92 | 99.68 | 123.63 |
| Average for Years of Record. | | | | | | | | | |
| January | 4.13 | ..... | 2.72 | ..... | 2.79 | ..... | 6.49 | ..... | 4.03 |
| February | 1.80 | ..... | 0.87 | ..... | 1.38 | ..... | 1.64 | ..... | 1.42 |
| March | 2.22 | ..... | 1.97 | ..... | 2.72 | ..... | 1.61 | ..... | 2.13 |
| April | 3.22 | ..... | 3.40 | ..... | 3.63 | ..... | 5.70 | ..... | 3.99 |
| May | ..... | 16.92 | ..... | 18.41 | ..... | 22.54 | ..... | 13.93 | 17.95 |
| June | ..... | 13.05 | ..... | 8.86 | ..... | 14.48 | ..... | 12.52 | 12.23 |
| July | ..... | 12.63 | ..... | 6.46 | ..... | 12.98 | ..... | 13.00 | 11.27 |
| August | ..... | 18.90 | ..... | 19.00 | ..... | 15.88 | ..... | 15.76 | 17.39 |
| September | ..... | 10.48 | ..... | 12.79 | ..... | 7.88 | ..... | 14.07 | 11.30 |
| October | ..... | 17.48 | ..... | 12.59 | ..... | 13.53 | ..... | 16.98 | 15.14 |
| November | ..... | 19.26 | ..... | 14.19 | ..... | 25.57 | ..... | 18.13 | 19.29 |
| December | ..... | 11.02 | ..... | 5.06 | ..... | 5.47 | ..... | 9.87 | 7.86 |
| Totals | 11.37 | 119.74 | 8.96 | 97.36 | 10.52 | 118.33 | 15.44 | 114.26 | 124.00 |

The author states (page 66) that, on the Atlantic side of the Canal Zone, "during the 3 to 5 months of 'dry weather,' the rains * * * cease almost completely." The average conditions during this time are shown by Table 13, and in Table 12 these facts are arranged for more convenient reference to the stations of long record which more nearly represent average conditions in the basin. From

Mr. Saville.

this it appears that the lowest amount that fell in 3 months' and 5 months' records was at Gamboa, while Cristobal and Bohio have minimum records of 2.14 and 9.54 in. (9.57 in.) for these periods. The average dry-season rainfall in inches is given in Table 14.

TABLE 14.

| Period. | Cristobal. 39 years. | Gatun. 4 years. | Bohio. 15 years. | *Gamboa. 26 years. | Alhajuela. 10 years. |
|---|---|---|---|---|---|
| December | 11.93 | 11.02 | 9.87 | 6.89 | 5.81 |
| January | 3.99 | 4.13 | 6.49 | 1.98 | 1.12 |
| February | 1.39 | 1.80 | 1.64 | 0.67 | 0.15 |
| March | 1.60 | 2.22 | 1.61 | 0.80 | 0.61 |
| April | 4.23 | 3.22 | 5.70 | 3.54 | 3.36 |
| 3 months | 6.98 | 7.24 | 8.95 | 3.45 | 1.88 |
| 5 months | 23.14 | 22.39 | 25.31 | 13.88 | 11.05 |

*About a mile north of Bas Obispo (Chagres).

In Table 15 is given the average discharge of the Chagres Basin (1 320 sq. miles) at Gatun for 1890-1908, inclusive. Gaugings were begun at Gatun in May, 1908, and the discharge figures before that time are estimated from the Bohio discharge, using relations which have subsequently been established. Previous to 1908, the minimum run-off of the Chagres River was that of the dry season, 1903.

TABLE 15.—DRY-SEASON FLOWS IN THE CHAGRES RIVER.

| | Cubic feet per second. | Inches. | | Cubic feet per second. | Inches. |
|---|---|---|---|---|---|
| January | 5 952 | 5.20 | July | 8 355 | 7.30 |
| February | 2 358 | 1.86 | August | 9 340 | 8.16 |
| March | 1 524 | 1.33 | September | 9 405 | 7.94 |
| April | 2 189 | 1.84 | October | 11 042 | 9.64 |
| May | 6 264 | 5.46 | November | 13 324 | 11.26 |
| June | 6 323 | 5.46 | December | 11 216 | 9.80 |

For the low-water flow, the following rates appear:

| | Average Discharge: | | Minimum Year: | |
|---|---|---|---|---|
| | Cubic feet per second. | Inches. | Cubic feet per second. | Inches. |
| 3 months | 2 008 | 1.70 | 930 | 0.78 |
| 4 " | 3 027 | 2.54 | 1 191 | 1.00 |
| 5 " | 3 691 | 3.12 | 1 739 | 1.47 |

From Table 15, "dry season" flows in the Chagres River, it would appear that the run-off is well sustained, and compares very favorably with the run-off in northern latitudes during the period of small rainfall. The 4 months' discharge, given for a minimum year such as may

occur once in 20 years, exceeds the dry-season rainfall, as given by the author in Table 1, by about 65 per cent. Mr. Saville.

The area and capacity of Gatun Lake for various elevations is given in Table 16; and the diagram, Fig. 5, shows these relations graphically.

TABLE 16.—AREAS AND VOLUMES OF GATUN LAKE.

| Contour. | AREA. | | VOLUME. | |
|---|---|---|---|---|
| | Square feet. | Square miles. | Cubic feet. | Acre-feet. |
| 90 | 4 835 349 042 | 173.44 | 205 910 598 090 | 4 727 056 |
| 85 | 4 554 874 320 | 163.38 | 183 136 226 495 | 4 204 228 |
| 80 | 4 274 399 597 | 153.32 | 160 361 854 900 | 3 681 401 |
| 70 | 3 670 295 420 | 131.65 | 120 698 379 810 | 2 769 476 |
| 60 | 3 099 155 666 | 111.17 | 86 791 124 380 | 1 992 450 |
| 50 | 2 528 937 595 | 90.71 | 58 650 658 080 | 1 346 434 |
| 40 | 1 970 738 955 | 70.69 | 36 152 275 320 | 829 942 |
| 30 | 1 425 899 458 | 51.14 | 19 169 083 260 | 440 062 |
| 20 | 813 349 126 | 29.17 | 7 972 840 340 | 183 031 |
| 10 | 384 834 783 | 13.81 | 1 981 920 790 | 45 499 |
| 0 | 11 549 376 | 0.44 | ..... | ..... |

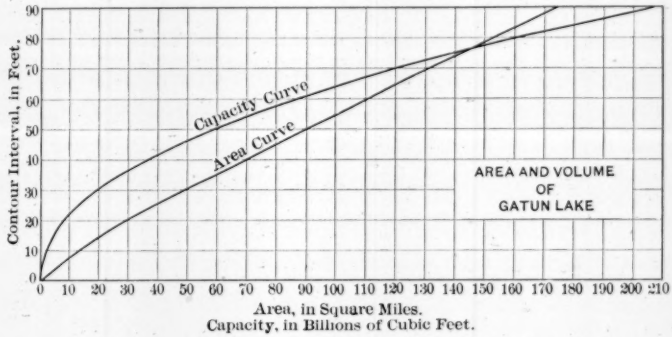



FIG 5.

In the "Report of the Board of Consulting Engineers for the Panama Canal, 1906," page 75, the Board adopted the evaporation figure, 0.24 in. per day, as given by General H. L. Abbot, U. S. Army, Retired, in his special report, Appendix E, page 195, of the same report. In his "Problems of the Panama Canal," page 177, General Abbot states that this figure (0.24 in.) was that also assumed by the *Comité Technique* for the Chagres Basin. Concerning surface evaporation and border evaporation, the average figure, 0.24 in. per 24 hours, has been used in all recent calculations, and appears to be a very conservative estimate, which may be rarely exceeded and then only for short periods.

Mr. Saville.

In his memoir, entitled "Hydrology of the American Isthmus," pages 579-80, A. P. Davis, M. Am. Soc. C. E., fully recognizes the faults of the "pan method" of determining evaporation which the author sets forth. He determined the evaporation for Lake Nicaragua by using the elevation of the lake itself after correcting for inflow and outflow. By this method, he found the evaporation to vary from 0.12 in. in February, 1901, to 0.26 in. in April, 1901. The mean of the two dry-season periods of 1900 and 1901 was 0.19 in. in 24 hours. This method, of course, would include not only evaporation from the lake surface, but also loss from border evaporation—"fly-off," as it is termed by the author. The author gives an evaporation varying from 0.10 or 0.12 in. to 0.30 in., with an average of 0.24 to 0.246 in. for the 5 months of dry weather. This appears to be more excessive than anything that has thus far been observed at Lake Nicaragua, by either the "pan" or "lake" method, or on the Isthmus. In Table 17 are given the records

TABLE 17.—EVAPORATION IN CANAL ZONE, JANUARY, 1907, TO JUNE, 1909, INCLUSIVE.

| Months. | 1907 | 1908 | | | 1909 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Bas Obispo. | Ancon. | Bas Obispo. | Cristobal. | Ancon. | Rio* Grande. | Bas Obispo. | Brazos* Brook. | Cristobal. |
| January | 5.175 | 3.348 | 5.617 | 4.868 | 3.348 | ..... | 3.240 | ..... | 4.868 |
| February | 5.072 | 6.557 | 5.729 | 7.958 | 3.728 | ..... | 4.295 | ..... | 5.353 |
| March | 6.538 | 6.997 | 6.290 | 7.557 | 4.931 | ..... | 5.005 | ..... | 6.445 |
| April | 6.486 | 5.921 | 5.475 | 6.930 | 3.883 | 5.960 | 4.710 | 5.366 | 6.468 |
| May | 4.681 | 3.219 | 3.175 | 2.570 | 2.451 | 4.205 | 3.517 | 4.597 | 3.868 |
| June | 3.125 | 3.046 | 3.415 | 3.184 | 1.916 | 3.417 | 3.284 | 3.806 | 2.498 |
| July | 3.152 | 3.017 | 3.250 | 2.822 | ..... | ..... | ..... | ..... | ..... |
| August | 3.582 | 3.203 | 3.425 | 3.192 | ..... | ..... | ..... | ..... | ..... |
| September | 3.358 | 3.049 | 3.635 | 3.327 | ..... | ..... | ..... | ..... | ..... |
| October | 2.988 | 3.256 | 3.875 | 3.324 | ..... | ..... | ..... | ..... | ..... |
| November | 3.599 | 2.414 | 2.730 | 2.700 | ..... | ..... | ..... | ..... | ..... |
| December | 4.896 | 2.942 | 3.445 | 4.056 | ..... | ..... | ..... | ..... | ..... |
| Totals | 52.602 | 46.969 | 50.051 | 52.488 | ..... | ..... | ..... | ..... | ..... |

* Tank floating in reservoir.

of evaporation extending over the period, 1907-1909, inclusive. The records from Ancon and Cristobal are from insulated pans, 10 in. in diameter and 3 ft. deep. The Bas Obispo records are from a concrete tank, 12½ ft. in diameter and 5 ft. deep. At Brazos Brook and Rio Grande, the records are from copper tanks, 4 ft. in diameter and 10 in. deep, floating in the water. In addition to these, there are at Rio Grande two other tanks similar to the one floating in the reservoir, one exposed on the border of the lake, and the other on the ground in the jungle. From these two pans information is expected for use in making comparisons and studying evaporation under various conditions. The records of the Brazos Brook and Rio Grande stations are incomplete as yet, not having extended through a full dry season.

Mr. Saville.

Besides the records of the pans, if one walks about the borders of the swamps and ponds in dry weather he finds that a rank tropical growth quickly covers the ground exposed by the receding water, effectually protecting it from the winds, and, as the humidity is high all the time, direct evaporation is very small. From the results quoted by General Abbot and Mr. Davis, together with the records of evaporation made on the Isthmus during the past two years, it appears that the evaporation figures used in the calculations for the lock canal are safely large, and that they include loss from surface evaporation and so-called "fly-off."

On page 69 the author makes statements from which it might be inferred that the temperature in exposed sunlight would ordinarily be from 125° to 130 degrees. Tables 18 and 19 show the exposed sunshine and mean monthly temperatures which have been recorded on the standard instruments which have been installed for this purpose.

TABLE 18.

| Month. | Monthly mean, in degrees Fahrenheit. | Monthly maximum, in degrees Fahrenheit. | Month. | Monthly mean, in degrees Fahrenheit. | Monthly maximum, in degrees Fahrenheit. |
|---|---|---|---|---|---|
| January | 95.1 | 101.8 | June | 91.5 | 98.0 |
| February | 97.9 | 100.5 | July | 91.6 | 97.5 |
| March | 97.9 | 101.8 | August | 92.4 | 97.2 |
| April | 98.8 | 104.4 | September | 92.8 | 97.2 |
| May | 96.2 | 105.1 | October | 92.2 | 97.0 |

TABLE 19.—MEAN MONTHLY TEMPERATURES FOR YEARS OF RECORD IN THE CANAL ZONE.

| Year. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ANCON (Panama). | | | | | | | | | | | | | |
| 1906 | 81.4 | 81.4 | 81.6 | 82.2 | 81.8 | 79.9 | 79.8 | 80.2 | 81.4 | 80.0 | 79.8 | 79.1 | 80.7 |
| 1907 | 80.2 | 78.8 | 81.4 | 81.2 | 82.0 | 80.0 | 81.0 | 81.0 | 80.6 | 79.6 | 80.0 | 81.0 | 80.6 |
| 1908 | 81.4 | 81.8 | 82.6 | 82.8 | 80.2 | 79.9 | 79.8 | 80.2 | 79.6 | 78.9 | 78.8 | 79.6 | 80.5 |
| 1909 | 79.4 | 80.3 | 81.4 | 81.4 | 79.4 | 78.8 | 78.8 | 78.7 | 78.9 | 78.6 | 77.0 | 78.0 | 79.2 |
| CULEBRA. | | | | | | | | | | | | | |
| 1907 | 76.8 | 75.2 | 77.8 | 77.3 | 79.4 | 77.8 | 78.0 | 78.6 | 78.6 | 77.6 | 78.0 | 78.0 | 77.8 |
| 1908 | 77.3 | 77.4 | 78.0 | 80.3 | 78.8 | 78.6 | 78.0 | 78.6 | 78.4 | 77.4 | 77.4 | 77.4 | 78.1 |
| 1909 | 77.5 | 78.2 | 79.2 | 79.9 | 79.1 | 78.4 | 78.7 | 78.4 | 78.6 | 78.5 | 76.4 | 76.5 | 78.3 |
| CRISTOBAL. | | | | | | | | | | | | | |
| 1907 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 79.4 | 78.9 | 78.0 | 78.4 | 79.8 | ..... |
| 1908 | 79.5 | 79.6 | 79.7 | 80.1 | 78.8 | 79.0 | 78.4 | 78.8 | 79.3 | 78.7 | 77.2 | 77.8 | 78.9 |
| 1909 | 77.4 | 78.9 | 79.3 | 75.7 | 75.9 | 78.7 | 78.4 | 75.2 | 79.1 | 79.0 | 76.5 | 76.6 | 77.6 |

Mr. Saville.

Table 18 and the diagram, Fig. 6, are given as an aid to judgment in evaporation estimates.

DIAGRAM SHOWING EVAPORATION AND ALLIED PHENOMENA
FOR BAS OBISPO STATION, DURING 1907, 1908, AND 1909
STATION ELEVATION = + 72. LATITUDE, 9° 07′ N., LONGITUDE = 79° 42′ W.

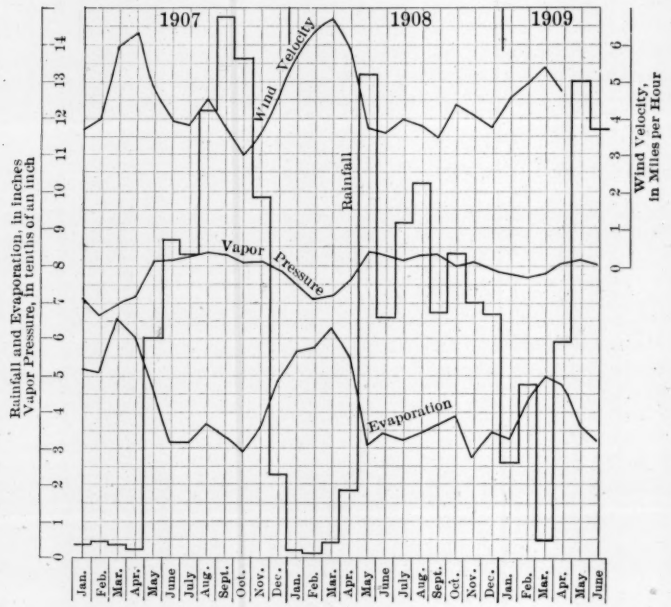



FIG. 6.

TABLE 20.—MEAN HUMIDITY—1908.

| Month. | Cristobal. | Bas Obispo. | Month. | Cristobal. | Bas Obispo. |
|---|---|---|---|---|---|
| January | 80 | 88 | July | 89 | 94 |
| February | 78 | 83 | August | 90 | 95 |
| March | 79 | 82 | September | 90 | 94 |
| April | 81 | 81 | October | 90 | 95 |
| May | 90 | 94 | November | 91 | 95 |
| June | 91 | 93 | December | 88 | 95 |

On page 72 the author gives the temperatures which he thinks will obtain in the lake. These are probably given for use in formulas connected with the movement of ground-water. From such records as have been obtained on the Isthmus, it would appear that the assump-

tions referred to above are in excess of the actual conditions. Table 21 is a record of the temperatures (in degrees, Fahrenheit) which have been taken in Rio Grande Reservoir in 1909. Mr. Saville.

TABLE 21.

| Depth. | June 29th. | July 31st. | August 28th. | September 29th. | October 19th. | November 25th. |
|---|---|---|---|---|---|---|
| Surface | 90.7 | 83.3 | 84.2 | 83.0 | 81.6 | 81.0 |
| 4 ft. below | 84.8 | 82.7 | 83.9 | 82.1 | 78.0 | 77.5 |
| 8 " " | 81.2 | 80.0 | 81.8 | 81.4 | 76.5 | 75.6 |
| 12 " " | 80.0 | 78.8 | 79.2 | 78.3 | 76.1 | 75.2 |
| 16 " " | 79.5 | 78.0 | 78.0 | 77.2 | 76.0 | 74.7 |
| 20 " " | 78.9 | 77.5 | 77.6 | 77.0 | 75.9 | 74.0 |
| 24 " " | 78.3 | 77.3 | 77.3 | 76.8 | 75.9 | 74.0 |
| 28 " " | 78.2 | 77.0 | 77.2 | 76.6 | 75.8 | 74.0 |
| 32 " " | 78.2 | 77.0 | 77.1 | 76.5 | 75.6 | 73.8 |
| 36 " " | .... | 77.0 | 77.0 | 76.5 | 75.5 | 73.8 |
| 40 " " | .... | .... | 77.0 | 76.5 | 75.4 | 73.8 |
| 44 " " | .... | .... | 77.0 | .... | .... | 73.5 |
| 46 " " | .... | .... | .... | 76.4 | 75.4 | .... |
| 48 " " | .... | .... | .... | .... | .... | 73.5 |
| Temperature of the air | 86 | 77 | 76 | 76 | 78 | 80 |
| Weather | Sunshine | Cloudy | Partly Cloudy | Cloudy | Partly Cloudy | Cloudy |
| Elevation of water surface | 220.5 | 223.9 | 233.2 | 235.3 | 236.6 | 237.9 |
| Time | 4.20 P. M. | 8.30 A. M. | 8.15 A. M. | 8.20 A. M. | 8.30 A. M. | 10.00 A. M. |

The author's statement that: "When a deep storage reservoir is formed on natural ground, there is usually quite a loss of water by percolation through its bottom and sides," does not seem to be founded on fact. If this were the case the storage of water for municipal and commercial uses would be almost prohibitive in its cost. The writer does not understand that any anxiety is being felt regarding the holding of water in the big Ashokan Reservoir for the New York supply, which has not been stripped, nor does he believe that there is any appreciable loss of water from the Croton Reservoir in New York or the Wachusett Reservoir in Massachusetts. The latter reservoir was stripped, but for other purposes than the examination of its bottom and sides for percolation. In fact, the very stripping of this reservoir should tend, if anything, to make it more porous, as the fine upper loam and soil is usually a much more effectual seal than are the under strata.

The percolation conditions between a canal artificially cut through varying strata and a lake formed in a natural depression of the ground would seem to be too far apart for comparison. The figures in Table 2, and quoted from the Report of the Isthmian Canal Commission, 1908, page 196, were given there merely as an extreme condition, to emphasize the point that, even under the impossible conditions of a cutting

Mr. Saville.

through porous soil, the rate of flow could not be disastrous to the stability of the dam. The same can be said of Table 3 and the data leading up to it, which appeared on page 134 of the same report. Extreme conditions were utilized to show stability, and it was expressly stated in the report that these conditions were not prevalent in the region examined. Contiguous bore-holes showed dissimilar characteristics, and the evidence seemed to point clearly to the formation of a comparatively few isolated lenticular deposits of exceedingly limited extent entirely surrounded by a large mass of very impervious material. The proposition to strip, examine, and make artificially impervious the whole 167 sq. miles of area to be flooded seems rather extravagant, even when one considers the Herculean proportions of the Gatun Dam.

The author states that the percolation can only be "guessed at." Even so, it has the basis of the judgment and experience of engineers who have been studying this particular problem for the past two years, using all standard methods for obtaining results. A "scientific guess," it was aptly termed by one of the Engineer-Commissioners. The author believes that a margin of safety should be assumed against risks of this kind. It is believed by all who have investigated this problem on the ground, who have actually seen the country, the excavations, and the sample borings, and who are familiar with natural conditions on the Isthmus, that a big margin of safety has been assumed. There is no lack of experimental data, and the methods and results will be referred to later. It is expected to show clearly that the investigations which have been made establish a safe basis for judgment, without reverting to general assumptions which may or may not be founded on fact.

The first five of his tentative assumptions are regarded by the author as self-compensating, and therefore they do not enter into the discussion. The author's assumption "*f*" is "that joints, seams, and fissures are generally abundant in sandstones, conglomerates, and other rocks like those found in the Canal Zone." This is a comparatively general statement for sandstones and conglomerates, and, were the strata on the Isthmus similar to the coarse sandstones and soft conglomerates of open texture that are found in the United States, the conditions might demand different treatment. Very little coarse sandstone and conglomerate has been found, but it was thoroughly traced by borings, and such precautions were taken as would prevent danger from this source. This stratum itself, however, in its natural condition and with its thick impervious covering of soil, would have probably offered no appreciable opportunity for seepage. Almost the entire mass of the rock found in the ridges is called argillaceous sandstone; it is of very finely-divided material, and contains very little grit. It is not very hard, is greasy to the touch, and some of it cuts readily with a knife,

showing the polished surface of chalk or soapstone. Tests made to determine its porosity showed that it was practically impervious to the flow of water. The seams and fissures in this rock are not abundant, nor do they appear to be of great extent. Diamond drill cores more than 7 ft. long have often been taken from the holes. In no case in all the borings has any fissure or cavity been found, in rock formations unshaken by blasting, that would suggest the possibility of a watercourse or the free passage for water that could be considered of serious moment. The surface covering all over the lake area is from 5 to 20 ft. thick on the valley sides, and the bottom layer, to the bedrock, is several hundred feet thick. This bottom covering extends southward from Gatun nearly to Bohio, a distance of about 8 miles in a straight line, gradually growing less in thickness and coarser in texture. It is formed of the clays and very finely-divided materials brought down the river and deposited in the almost stagnant waters which were anciently found below Bohio. This condition appeared both when the region was depressed and the sea made in, and when it was elevated and a large fresh-water lake was held back by the ridges at Gatun. It also obtains at the present time when the water backs up at Gatun, due to freshets. In any case, the deposit below Bohio is of such a character that it is not probable that this area could be made more impervious by any reasonable artificial methods. Due to this same cause, the bottom and sides of the proposed lake will become more and more impervious as time goes by and the sedimentary deposits slowly increase. On the sides and crests of the ridges, the rock has gradually weathered to a red clay. This is practically impervious at the surface, but grows more and more open until it reaches the firm and impervious rock. Immediately on top of this rock the material is coarse and open. Here is found the condition for percolation and ground storage of water. The entire ridge on the west side of Gatun Lake has been meandered for low places in the divide and from Lagarto to Gatun, where the ridge is lowest, especial investigations have been made, the results of which will be described later. North of Lagarto, the ridges become higher, and the rock changes from the argillaceous sandstone to a trap formation. Mr. Saville.

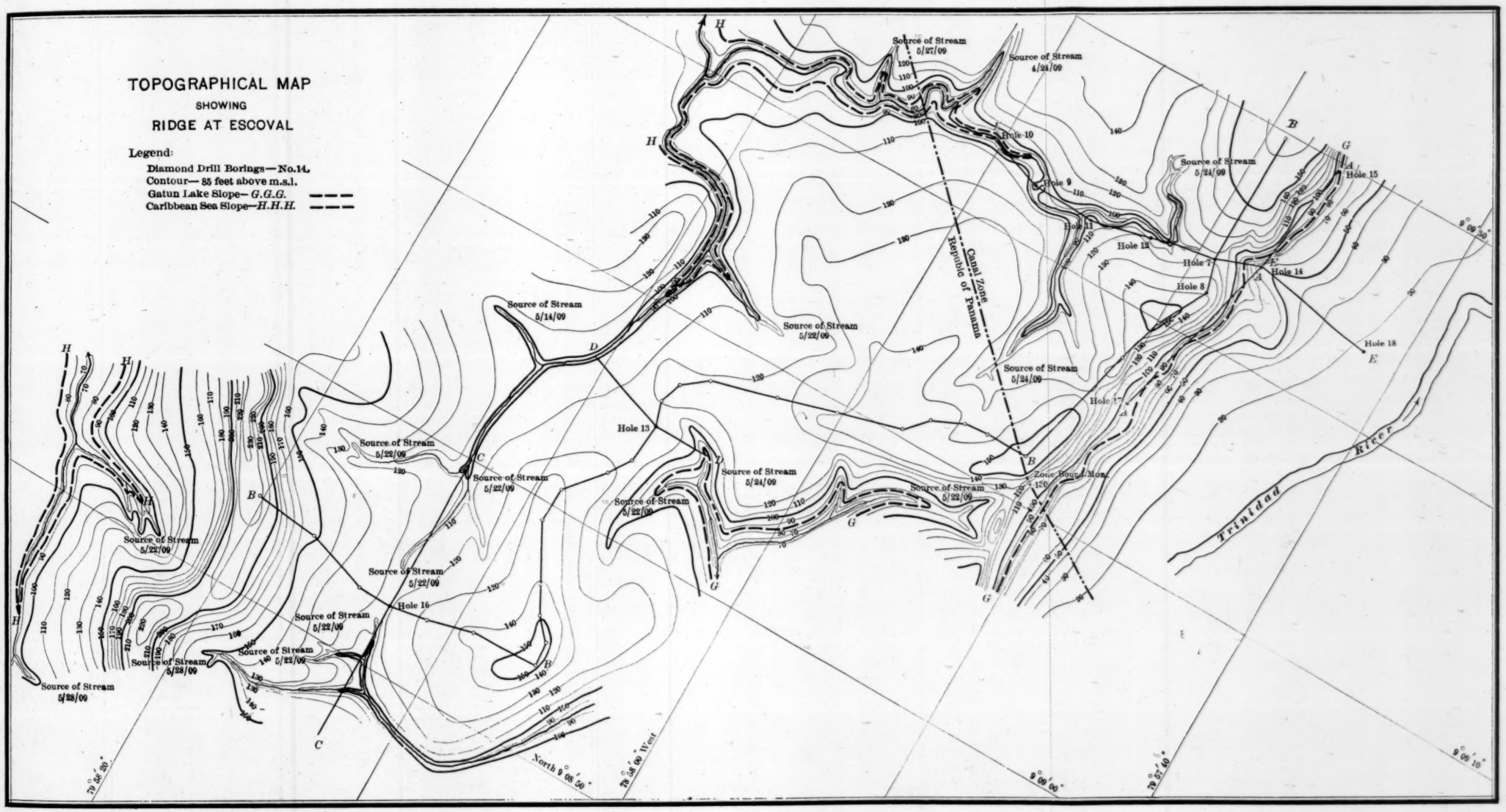
In assumption "*g*," it is stated that "the absence of lakes and springs in the whole region strongly indicates either good drainage or ample underground communication with water-absorbing strata." As intimated above, no strata have been encountered in any of the borings in the ridges which, by a stretch of imagination, could be called "water-absorbing," except the layer of disintegrated rock lying immediately on top of the firm formation. If by good drainage the author means surface conditions, it can be stated that the topography of this entire basin shows almost perfect conditions, and a study of a relief map will show why no mountain lakes appear in this region. Regard-

Mr. Saville.

ing the absence of permanent springs and surface-water storage conditions, the author is in error. All the high ridges furnish perennial brooks of greater or less size, due to rainfall conditions, and these are fed by springs rising from the disintegrated rock layer previously referred to. Many of these springs take their rise at an elevation far above that of the proposed lake surface, and continue to flow throughout the dry season. Their torrential flow during the wet season has cut their courses deep through the overlying clay covering and down to the firm rock, over which they run in a series of rapids, forming, in the dry season, a succession of falls and pools. That these streams continue to be fed and to run down the hillsides in periods of little rainfall is evidence of the water-tightness of the rock in the ridges. On the Caribbean side of the ridge, and extending from Lagarto to Escoval, there is an immense swamp, at an elevation of 68 ft. above sea level and from 50 to 55 ft. above the elevation of the Trinidad River Basin level on the other side of the ridge. There is water in abundance in this swamp throughout the dry season, and borings show that it is in a depression of the rock. If these ridges were permeable to any extent, this swamp would cease to exist, as its waters would seep through into the Trinidad drainage. The whole Trinidad Basin in the limits of the proposed lake is a series of extensive swamps, which are filled with water, and open lagoons with a surface elevation of from 8 to 15 ft. above the waters of the rivers into which their overflow drains through small brooks and cuts in the banks. The Gatun River Basin furnishes a similar example of swamp and stream flow. Similar conditions also are found on Lirio Lagoon, opposite Culebra, and in Rio Grande Reservoir. Quite extensive lagoons are found in the vicinity of Bohio, above the ordinary elevation of the Chagres River, and an artificial pond several acres in extent was formed by an old French dump near the French storehouses on the west side of the river. This pond, fed only by comparatively local run-off, has a considerable depth of water during the entire dry season, and is utilized as a station for testing the current meters used in the river gaugings. The deep cuttings for the canal have disclosed no water-bearing strata, either of rock or gravel, and the bottom of the excavation in many places is far below streams and watercourses which are comparatively near the edge of the cut.

A brief description will now be given of the borings which have been made in the ridges for the particular purpose of investigating the seepage conditions to which the author refers. In running out the ridge line, low saddles were found in the divide at the places called Escoval (El. 118), Arroya (El. 111), Cano (El. 87), and Lagarto (El. 106). Investigations with a diamond drill were made, together with comprehensive tests for loss of water at various elevations. Complete topographical maps were made of the immediate vicinity of the

PLATE V.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1145.
SAVILLE ON
WATER SUPPLY FOR THE LOCK CANAL AT PANAMA.



low places, and holes were located for drilling where it was thought the worst conditions might be found. Plate V is the topographical map showing the borings at Escoval, and is typical of conditions and methods elsewhere. Fig. 7 is a section through the ridge at Escoval. The investigations of these ridges show impermeable materials; very little water was lost in any of the bore-holes, and only for short and intermittent periods. In all cases where the elevation of the ground permitted, the ground-water stands naturally in the holes at elevations higher than the surface of the proposed lake. This condition of ground-water is taken as an indication of the imperviousness of the materials forming the ridges. In the Cano Saddle the elevation of the surface and the overlying disintegrated rock is such that a concrete cut-off wall or other impervious structure will probably be necessary to prevent outflow. This will be a comparatively simple affair, reaching only to a maximum depth of 25 ft., and its length will be comparatively short. At all other places the ridge is of sufficient height and thickness to confine the lake safely. The thinnest rock section, except as noted above for artificial protection, is more than 400 ft., and through a fine-grained impervious stratum. The maximum depth explored was about 100 ft. below sea level, and most of the holes were driven from 10 to 40 ft. below this datum. The surface conditions were carefully noted, and, although the sides and beds of the streams are exposed to the torrential rushes of large quantities of water, the erosion is very little, which is excellent evidence of the permanency and resistance of this formation. Mr. Saville.

The following statements summarize the methods of procedure which have been undertaken to obtain information on which to base judgment as to the character of the materials in the bottom and side ridges of the basin which is to hold the proposed Gatun Lake. The bottom deposits were thoroughly examined, and the results and conclusions are given in the Report of the Isthmian Canal Commission.* A final report on the borings in the Escoval Saddle is to be found in the Report of the Isthmian Canal Commission, 1909 (page 201), which will soon be issued. The work at the other saddles—Arroya, Cano, and Lagarto—has been completed since submitting the annual report. Summaries of these reports are given above. Directions were given by the Chief Engineer to examine thoroughly the ridges on the west side of Gatun Lake, both for loss of water by seepage and to develop what construction, if any, would be necessary in the low portions of the ridges.

The ridge line southward from Gatun was run out by a survey party. Following this, all places in the ridge which were either at a less elevation than 150 ft. above mean sea level or had a thickness of less than 2 000 ft., were carefully explored. At least two independent

* Appendix E, 1908.

Mr. Saville.

parties carefully investigated these places, paying especial attention to stream flow, rock outcrops, and general topography. From this study the lowest and thinnest places were chosen, detailed topography was taken, and positions for diamond drill holes were located from the plans. These holes were drilled with particular care to get information regarding their entire depth, and especial precautions were taken and tests made to ascertain the action of water on the formation. From personal investigation on the ground, and knowledge from the seepage tests and study of the samples, the writer believes that the materials as found in the ridges at Escoval, Arroya, Cano, and Lagarto are representative of the formation in the ridges about Gatun and north thereof to the trap-rock region near the southwest end of the proposed Gatun Lake.

On the south and east borders of the lake no losses by percolation can be apprehended, on account of the height and thickness of the ridges. On the northwest side, for a distance of about 9 miles from Gatun, the ridges have not yet received the careful attention given south of this point. Some exploration and investigation has been made there, however, and nothing has been found that would cause apprehension. It is believed that the investigations which have been made are more thorough than is usual, even with Government work, but were justified by the importance of this undertaking. From these investigations nothing has as yet developed that would suggest increasing the figures used by the Consulting Board of Engineers. The loss of water by seepage, however, has not been "authoritatively dismissed as 'an impossibility,'" as stated by the author, either by the Board of Consulting Engineers or in subsequent calculations, for on pages 75 and 195 of the Report of the Consulting Engineers an amount equivalent to 77 cu. ft. per sec. is cited, and it is the writer's impression that 85 cu. ft. per sec. is the figure now used in calculations.

To sum up: Evidence of the impermeability of these ridges is drawn from the following:

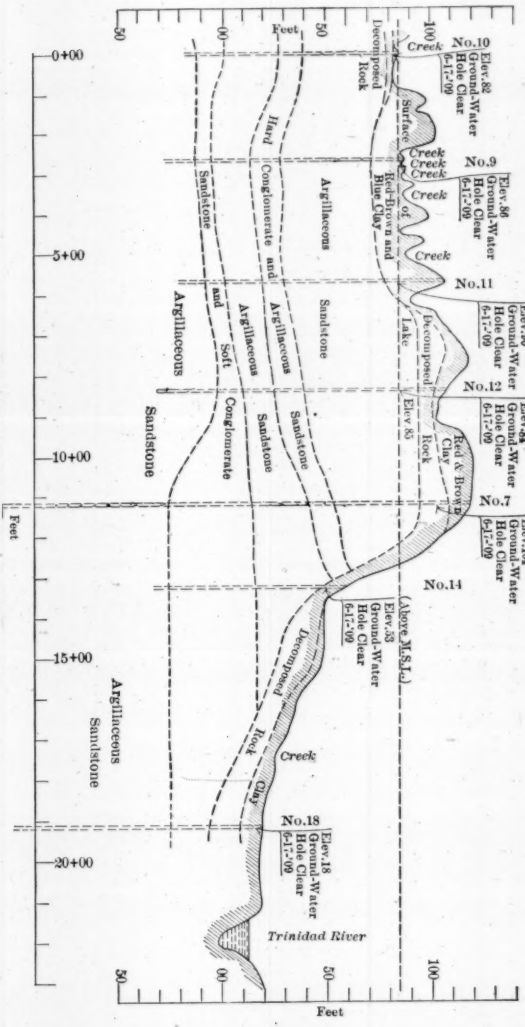
(*a*).—The small amount of wash-water lost and the ease with which it was regained during drilling;

(*b*).—The fact that the holes could be filled with water and kept filled to the surface of the ground, and that the only loss at all appeared in the disintegrated layer overlying the rock, which, in all cases, except at Cano, mentioned above, is at an elevation higher than the proposed lake surface;

(*c*).—That the bore-holes to a depth of from 100 to 120 ft. were easily bailed out with the sand pump;

(*d*).—That water did not appear on the face of the ridges during pumping and filling the holes, although this exposed portion was at times less than 150 ft. away;

Mr. Saville.




BORINGS AT ESCOVAL IN 1909.
SECTION ON *EE* OF TOPOGRAPHICAL MAP.

Fig. 7.

Mr. Saville.

(*e*).—That water appeared only slightly in one case in a neighboring hole when one hole was being filled;

(*f*).—That when bailing ceased and the holes were clear, the water gradually rose to a higher elevation in the holes than the proposed lake level (due probably to downflow from the disintegrated rock layer above), and remained in this position;

(*g*).—That the exploration has been thorough and to reasonable depths, and that comparatively compact and dense rock has been penetrated;

(*h*).—That streams continuous throughout the dry season are of common occurrence, coming down from the tops of the ridges and being fed by perennial springs;

(*i*).—That extensive swamps, lagoons, and ponds are frequent at high and low elevations, and in positions to drain readily if the formation permitted; and that the swamps do not dry up during the dry season, but are continually filled with water.

Finally, the writer desires to quote the opinion* of General H. L. Abbot, who, more than any other engineer, has studied the hydraulic conditions that relate to the Isthmian Canal, and is able to speak with the authority of intimate knowledge. What he has said regarding the conditions above Bohio applies with even more force to the region below that point:

"In the case of the Chagres Valley, the geological examinations give every promise that the water impounded would be retained with even less infiltration than usual; but following their habit of neglecting nothing which could throw light upon the problem, the Engineers of the New Company instituted what is perhaps the most elaborate study of the ratio between downfall and drainage that has yet been made in a tropical valley like that of the Chagres above Bohio. The results leave no doubt that the subsoil is fully saturated with water, and that no open route exists for any considerable subterranean escape. On the contrary, the stream receives large contributions from this source.

"In round numbers, it appears that, of the entire rainfall in the basin, about one-third evaporates, another third flows off directly by the bed of the river, and the residue, after a retardation of perhaps three months by its passage through the soil, ultimately reaches the river as ground-water. During the dry months it supplies much the larger part of the flow. In fine, the conditions of this tropical basin, as compared with those existing in the northeastern portion of the United States, indicate per square mile about 2.5 times the rainfall, 3.3 times the outflow, and 1.5 times the evaporation."

Tables 10, 12, 13, 17, Figs. 3, 5, 6, and Plate V, which accompany this discussion, are from the Annual Report of the Isthmian Canal Commission for the year ending June 30th, 1909.

* "Problems of the Panama Canal," p. 164.

Mr. Sorzano.

JULIO F. SORZANO, M. AM. SOC. C. E. (by letter).—The writer highly appreciates the fact that five eminent engineers should have had the patience to read his paper, and the kindness to criticize it in full. In replying to them now, he finds himself somewhat single-handed—one foil against five keen sabres—and, on that account, he begs forgiveness if, like a swordsman when crowded, he has had to use a little *riposte* between his parries.

The importance of the various questions discussed, and the detailed and specific manner in which each criticism has been presented, from different points of view, have compelled the writer to answer in the same manner—paragraph by paragraph—in order that no important point may be overlooked. He only regrets not to have been able to group and condense as much as he would have wished.

### CLEARANCE FOR NAVIGATION, AND DEPTH OF WATER.

The writer takes pleasure in admitting that if these questions referred only to the construction of locks for inland navigation, no better authority could be found to decide on the dimensions to be adopted than Colonel Hodges, who has had such good opportunities to study and build some of the finest river locks. In a canal for deep-sea navigation, however, the problems are more complicated, and of such importance in regard to their adaptation to the necessities of general shipping and naval service, that perhaps the opinion of those who will use the Canal may also be of some importance.

For this reason, before writing the paper, the writer thought it wise to seek the advice of men likely to be most interested in the future use of the Panama Canal: naval officers, managers of steamship companies, navigators, captains of transatlantic steamers, presidents of marine insurance institutions, ship-brokers, agents, merchants, shippers, commanders of battleships, pilots who handle the largest craft afloat, etc.

The data thus obtained, during three months of an arduous investigation, suggested the "clearance" figures given in the paper. The writer had originally assumed only 2 ft. clearance in the still waters of the canal proper and 4 ft. for the open lake; but, after having heard such experts, he saw the necessity of adopting clearances of "3 ft. in the canal proper and 6 ft. in the lake," believing that in a question of such importance, the opinions of those who are to navigate the canal should have paramount weight.

The officers of the Navy, the seafaring men, captains, navigators, pilots—all those consulted—disagree, in their ideas, with Colonel Hodges on the small clearance that he considers sufficient for safe navigation.

As for passing vessels drawing "practically every inch of water which the elevation of the sill will permit, and sometimes, strangely

Mr. Sorzano.

enough, a little more," as Colonel Hodges says, this cannot be considered seriously in a waterway intended to serve our Navy and our commerce in competition with the rest of the world and for "all time to come."

The writer has a photograph showing a lake steamer "stuck" on the sill of one of the St. Mary's Falls locks, with several tugs around her, puffing in their strenuous efforts to release her. She is probably one of those trying to navigate in less water than her draft. It is to be hoped that the water supply in Gatun Lake will offer to our Navy something better than that in the future.

In this matter of clearance there is also a point which the writer has not seen mentioned anywhere in connection with the Panama Canal, namely, the provision to be made for passing vessels damaged by stranding, or for battleships injured in action or otherwise, and drawing perhaps 4 or 5 ft. more than their ordinary sea-going draft. As one of the most important uses of the Panama Canal is for our Navy, it might be unpardonable to overlook this point.

Colonel Hodges' clearance ideas are applicable only for vessels on perfectly still waters and in calm weather; but the Canal is to be used, not during good weather only, but at all times. If the service is to be interrupted, not only by fogs, but by storms, high winds, northers, high waves, etc., the Lock Canal will be useless for a great part of the time, and perhaps when most needed.

The foregoing considerations, and the belief that the difficulty of steering a large vessel when there is but little water under her keel adds considerably to the dangers of navigating submerged channels like those in Lake Gatun, confirm the writer in his opinion that the clearances suggested in the paper are advisable.

The arrangement of the tables, however, permits the reader to adopt his own figures and deduce his own conclusions.

The writer did not suggest 3 ft. clearance for the locks, as Colonel Hodges says. The clearances named were only for "the canal proper" and on the lake, where vessels will have some speed. The paper also said:

"Any reduction of such clearances will increase proportionately the risks and dangers of navigation through the submerged channels in Lake Gatun, particularly on the rocky bottoms and short navigating 'legs' above Bohio, on account of the heavy fogs that will frequently prevail there."

*Dimensions of Future Vessels.*—Colonel Hodges says that "anyone is at liberty to prophesy," etc. The writer did not know he was prophesying when he gave his reasons for believing that the dimensions of vessels may continue to increase in the future. It is well to remember that in 1906 the judgment of the authorities responsible for

the Lock Canal dimensions, as to the probable future needs of navigation, was that: Mr. Sorzano.

"Locks 95 ft. wide with a usable length of 900 ft. will fully meet the requirements for both commercial and war ships, for a long term of years."

That was said only three years ago; but, since then the increase in marine dimensions continued to be such that, before the three years had elapsed, the Navy Department had to declare those dimensions inadequate and insufficient. The locks—in spite of the eminence of the men responsible for their original dimensions—have had to be enlarged three times since their adoption; to-day, they are not half finished, and yet they are smaller than the locks now being built by Germany at Kiel,* and by the United States at St. Mary's Falls for lake navigation. The judgment of the Lock Canal authorities, evoked by Colonel Hodges, evidently did not result in an accurate estimate of the possibilities of the future, even within three years; will their assumptions for the greater future be more accurate?

The writer did not attempt to "prophesy," nor even prognosticate what the dimensions of future vessels will be; he said, very plainly, "he will not presume to predetermine here, even approximately, what the dimensions of such future vessels will be." His presages were only based on the developments of the past, and on the assumption that "if the same gradual average increase be kept for 30 years more, etc., etc." He has no objection, though, to having his forebodings taken as prophesies when analyzing elements of risks in the future, on matters of such transcendental importance to the country.

*Draft of Vessels.*—The Panama Canal is not being built to pass barges and tugs only from Colon to Panama. It is intended to give convenient passage to all sizes of naval and commercial vessels coming from all parts of the world, and on their way for several thousand more miles at each end of that waterway. Any ship, in order to navigate such long routes on the great oceans, must have not only tonnage enough to carry her own fuel, but sufficient cargo capacity to be a paying carrier. To do this, and be safe on the deep seas, she must also have beam and draft. With the exception of pleasure yachts, vessels drawing less than 22 ft. could not do such service and afford to pay the toll through the canal. Vessels of such small draft will not be built hereafter to carry merchandise on such long routes, the tendency being to build as large and deep as possible, and bigger every year. The average tonnage of ships passing through the Suez Canal (6 000 tons) has increased more than 100 tons per year, and is now limited only by the depth of that waterway. On the Panama route, with its longer stretches, the minimum economical sizes will

*Of unlimited length, and 147 ft. wide.

Mr. Sorzano.

not be less than 6 000 tons per carrier, and with a minimum draft of 25 ft.

This is a very important point to bear in mind in connection with Colonel Hodges' idea of using the intermediate gates for the greater part of the future traffic. His proposed manipulation of gates and contents of locks will not permit the passage of the small commercial ship which could use the canal economically. The tramp carriers now built are more than 350 ft. in length and have a draft of 25 ft.

As for the largest carriers probable, inasmuch as the writer has already been taken to task for prophesying, he will venture now to express the belief that, if the dimensions of the locks did not prevent it, the next 25 years would produce vessels 1 185 ft. in length, having 115 ft. beam and more than 45 ft. draft. Such carriers, built with a longitudinal central truss extending from end to end and from keel to upper deck, could ride over four of the longest waves. Driven by direct combustion or gas engines, with liquid fuel, no boilers, perhaps by thermo-electrical motors, these leviathans, with a small crew of well-paid men, would make it possible for our great corporations to deliver in the Orient, our coal, oil, railroad materials, etc., at the lowest possible cost. The Lock Canal, as now being built, will not accommodate such large carriers; the Suez Canal, now being incessantly enlarged, will some day give passage to still larger vessels.

*Depth of Harbors.*—The writer does not share Colonel Hodges' anxiety as to the possible effect of the increased draft of vessels on harbors, the expenses of mankind, etc. It is certainly not admitted by shipbuilders that craft will not be made larger in the future because the majority of ports could not receive them, as Colonel Hodges says.

The fact that such ports as Bordeaux, Havre, Antwerp, and a hundred harbors of Europe could not have received at their docks a vessel of the size of the *Lusitania,* did not prevent England from building, not only that vessel, but the *Mauretania,* the *Olympic,* the *Titanic,* etc., and will not prevent her from producing larger ones if commerce should demand it. If, in the future, Liverpool and other great ports of England should not be able to receive larger boats than the *Olympic* and *Titanic,* New York, Boston, Seattle, Portland, or San Francisco will not be prevented from berthing the still larger craft that the future may produce.

The writer remembers well that not longer ago than the early Eighties, the same arguments as those advanced now by Colonel Hodges were used to predicate that no vessels as large as the *Great Eastern* would ever be built, because the harbors of the world could not receive them. How fallacious such arguments were, is well proven by the great number of vessels larger than the *Great Eastern* now afloat.

Mr. Sorzano.

If that contention had ever been sound, three-fourths of the world's large carriers would never have had more than 12 or 14 ft. draft.

It is well known to those who ship goods to foreign countries that, in the great majority of cases, vessels on arriving at their destination go only to anchorages, where lighters come to receive and deliver the cargoes. This is done all over the world, when necessary, and few ports have facilities to do anything else. The writer has chartered a number of vessels from New York, and delivered thousands of tons of machinery and steelwork at distant localities, where the depth of water did not show even a 5-ft. draft.

For long-distance sea transportation, the important elements that influence the size of vessels, in addition to commercial and shipping conditions at the home port, are: (*A*) the intermediate obstacles, and (*B*) the distance.

*A.—Intermediate Obstacles.*—An example will perhaps make this clear. Suppose a vessel is required for the service between New York and Chefoo *via* the Horn. In practice, such a carrier will be chosen in accordance with the shipping conditions at New York and the long distance to be covered, and not according to the depth of water alongside of piers at Chefoo. At the latter port she will go to an anchorage, unload on lighters, and receive in the same manner her return cargo.

The same vessel, loaded from New York to Chefoo, *via* the Suez Canal, for example, will have her draft limited by the "intermediate obstacle," namely, the depth of the Suez Canal, and will be chartered as large as that canal will permit, irrespective of the pier difficulties at Chefoo, or the facilities at New York.

The few ports having their anchorages separated from the rest of the commercial world by shoals or bars may have to do some extra dredging in order to benefit from the large carriers, but the expense to which Colonel Hodges believes "mankind would be forced by such development" would be considerably less than the accumulated extra cost of the higher freight rates that would result, if all carriers had to remain small in order to meet the limitations of those few ports or the restrictions of an inadequate intervening canal.

*B.—Distance as a Factor.*—The longer a route—without recoaling—the larger a steamship must be in order to be able to carry fuel enough to complete her voyage. The ratio of that fuel capacity to the net cargo transported is the most important factor confronting the marine architect. The simple consideration that, if the size of a freighter is increased, for instance, 10 times, its fuel consumption would increase only 5 times (neglecting all other economies due to a larger unit), indicates the absolute necessity of building "as large as possible" for extra long routes, in order to reduce the cost of transportation "per ton of freight carried."

Mr. Sorzano.

Any canal with unalterable locks or other immutable restrictions preventing the construction in the future of such large carriers, will not only destroy the natural advantages of all the favored harbors that could receive such large carriers, but will indirectly affect mankind by retarding progress.

*Obstacles.*—This is one of the most important points in the canal problem; it is not simply a commercial question; it involves the highest engineering considerations, if engineering is the application of the resources of Nature for the benefit of Man.

The river engineers of the United States who, after years of experience in inland waterways, have naturally been brought up to submit to the depth of long shallow rivers as natural, insurmountable limitations, and who have had always to deal only with uniform craft built to meet such limitations, cannot realize, it seems, that the conditions of inter-oceanic navigation are totally different. They seem to forget that the canal at Panama will be a short link, only 50 miles in length, connecting two vast oceans, with half the circumference of the earth on each side, built to pass vessels of all sizes, converging from all quarters of the globe to that canal. Under such conditions, the angle of vision must be enlarged, not only in proportion to these features, but to the possibilities that will develop by the opening of the canal itself.

In cutting the continent in two, American engineers are assuming an immense responsibility toward future generations. In undertaking that task, they are capable of being, and ought to be, up to its magnitude.

When, as Mr. Grunsky says, future generations inquire why American engineers selected the only spot between two oceans where a sea-level waterway could have been built and economically operated, to build an inferior waterway, historians will indeed be at a loss for a satisfactory answer, particularly when they find in the *Transactions* of this Society the opinion expressed that "Locks are not added to canals to improve them." Mr. Grunsky deserves our thanks for having coined that lashing sentence.

When the writer, in March, 1909, as a member of the Committee of the New York Chamber of Commerce, began an investigation of the Canal problems, he was confronted with the following facts and disturbing features of the Lock Canal project:

*I.*—That the Lock Canal is too narrow, and narrower than the Sea-Level Canal. For, inasmuch as a waterway is not wider than its narrowest part, the Lock Canal will be only 110 ft. wide. As the locks are to be operated as a double-track system, their added lengths give a total distance of more than 3½ miles of canal only 110 ft. wide, between huge, solid, vertical concrete walls which cannot be moved

without being first destroyed, thus immutably limiting the canal to that 110-ft. width.* Mr. Sorzano.

*II.*—That the width of the Sea-Level Canal would be, absolutely, in no place less than 150 ft. in its narrowest part, and could be enlarged at any time, without inconvenience to navigation, without destruction, and without limit.

*III.*—That the annual expenses of operating and maintaining the Lock Canal will exceed those of the Sea-Level Canal by about $6 000 000, due to the extra cost of operating and maintaining, in the tropics, the twelve locks, their appurtenances, and the accessories inherent to the Lock Canal system; and also due to the enormous annual sinking fund necessary to renew and replace every few years the colossal amount of metal work, machinery, and expensive appliances used only in the Lock Canal, and for which there would be no counterpart in the Sea-Level waterway. This extra cost of operating the Lock Canal will be a perpetual, extra annual charge.

*IV.*—That the possibility of an insufficiency of water during the "dry season of dry years" had not been accurately investigated, in view of the requirements of the future. Inasmuch as the catchment basin now available and accurately measured is the maximum possible, being the extreme limit of its crest's maximum periphery, there is no possibility of future enlargement of that basin. Its minimum run-off is, and will be for all time to come, the limit of the water supply for all the uses of the Lock Canal.

*V.*—That the foregoing features, after being established by construction and by natural existing conditions, will, by the immutability of their limitations, have an element of perpetuity which will make the Lock Canal forever inadequate for the probable needs of the future.

It was to ascertain this feature that the paper was written, inviting criticisms from which it was hoped to gather authoritative data by which to settle the question. It should be stated here that the paper was not to prove insufficiency of water in Lake Gatun during "the average years of plenty," nor during years of flood, but to ascertain the possibility of lack of water in the "dry months of dry years," such as recur on the Isthmus at frequent intervals.

*When using the locks, large vessels must be fastened to the walls on each side by at least four mooring lines. Allowing 3 ft. of play on each side as space for a man to reach the mooring dogs and handle the lines between a 30 000-ton battleship and the vertical walls of the locks—a minimum considering the very high lifts and the speed involved—the canal will not offer safe passage to any vessel of more than 104 ft. beam, and this with the supposition that such enormous craft can be kept perfectly in the center of the lock, while going up and down 30 ft., with a tumultuous inrush of 3 500 000 cu. ft. of water under her keel, at the rate of 1 600 000 cu. ft. per min.

Any irregularity in paying out the lines, or the parting of any one of them, may cause a serious accident. To prevent this, a wider play is indispensable, say 6 ft. or a net usable width of 98 ft.

A carrier with 100 ft. beam is under study in Europe; the United States is constructing a battleship with 95 ft. beam, and the excavations for the locks are not even finished. The sea-level canal at Suez, opened 40 years ago, was passed freely by the floating dock *Dewey*, having a beam of more than 120 ft. Are we building a first-class canal?

Mr. Sorzano.

This paper was to ascertain—on the safe side—whether in such "dry months of dry years" the water remaining in Lake Gatun would be sufficient to maintain in it the depth required for safe and convenient navigation of the canal at all times. The critics have not considered the problem from this, its only, point of view.

### Alhajuela and Gamboa Dams.

The Alhajuela Dam was only mentioned as one of the expedients to which the nation might resort to reduce the great cost of pumping and re-pumping the brackish waters back into the lake after having used them in the locks.

The Gamboa Dam would have regulated the Chagres River, not at an expense, but at a large annual profit; not only during the construction of the canal, but for all time to come.

Large hydro-electric plants are now being built all over the world, at great cost, in order to utilize water-power and distribute its energy with profit. This nation, on the contrary, is now spending millions to create a lake in which more than 150 000 h.p., and other even larger and more valuable assets, will be forever annihilated.

### Methods of Calculation.

The method of calculating the water supply, suggested by Mr. Grunsky, is about the same as that used hitherto by the Lock Canal engineers. There is no objection to it, provided the units assumed are accurate, complete, or on the safe side, and in accordance with the conditions on record. This method, however, does not permit of obtaining readily the different solutions according to the ever-changing conditions due to the variations of time, level of water, rainfall, run-off, etc., etc.

By it, one may ascertain what would remain, in a given case, after having combined (or eliminated) known, doubtful, and unknown elements, and, if there is water enough, allow for them; but it does not give the intermediate solutions, in regard to depth of water in the lake at any time.

The writer's method, on the contrary, divides the problem into four main parts, in columns, with fourteen elements in each. This gives at least fifty-six possible results, according to the units chosen. With this arrangement, if any item should seem to the reader to be too large, or inaccurate, he can change it to suit his judgment or his own data; the result will be affected only to the extent of that alteration, and will show clearly its importance as a factor in the total.

For example: It is well known that evaporation during the dry season will vary from month to month, with the "peak" at some shifting point in the middle of the season; it is also obvious that the level of the lake, and with it, its net area and other elements, will also

vary as the season advances. These changes can be followed and studied, with the writer's method of correlative elements, and the depth of water at various periods can be calculated. Mr. Sorzano.

Whatever system may be preferred, it is necessary that the original data should be as accurate as possible, or, at least, be on the safe side—so as to avoid misleading errors.

In this respect, the figures assumed by Mr. Grunsky might be seriously criticized. He takes:

| | | |
|---|---|---|
| The lower water flow above Gatun during four dry months, to average about | 1 200 | cu. ft. per sec. |
| And the rain on the lake during the same months | 100 | " " " " |
| Total | 1 300 | cu. ft. per sec. |

This is entirely too much, when correcting figures of a "dry season in dry years" for a locality where dry years have shown run-offs of only 800 and 900 cu. ft. per sec., and where the net available amount will be considerably less, as will be demonstrated later, under separate headings.

Mr. Grunsky inadvertently overlooked, also, the fact that the 1 200 cu. ft. per sec. of dry years like 1908 and 1903, already include the rain on the lake (or which would fall on it if it were there); in fact, that amount covers all that can possibly be received above Gatun.

There is another element which Mr. Grunsky has not considered in his calculations, and that is the reduced run-off occasioned by the reduced seepage basin, caused by filling the lake.

Under a separate heading, the writer has discussed this important matter in full. In that analysis it is shown that the reduction of the dry months' replenishing supply for Lake Gatun will amount to from 100 to 150 cu. ft. per sec., or about 12½% of the amount that would be available if there were no lake.

It is easy to conceive that if Lake Gatun could be filled up to the edge, or periphery of its maximum catchment basin, 1 320 sq. miles, and kept full at that extreme level, there would be no dry-season run-off, and in consequence no dry-season inflow into the lake after the last rains had fallen. This would be a 100% reduction. Lake Gatun at the 85-ft. level covers 165 sq. miles, or 12½% of the seepage basin. The reduction ought to be in the same proportion if other conditions remained the same. But those 165 sq. miles are in the lower part of the basin where the alluvial soils are thicker and more water-bearing than in the higher grounds, and where rainfall is also more abundant. Hence there is a larger flow.

This loss of inflow by "water occupation" or by reduced useful storage, as well as the gains by diminished swamp evaporation, etc.,

Mr. Sorzano.

have been carefully considered by the writer; but as the balance sheet between losses and gains would have favored his figures so much, he did not complicate his tables with them. A simple consideration of the increased evaporation on the 75 or 80 sq. miles of forest that will remain standing in Lake Gatun, compared with the 10 or 20 sq. miles of swamps in the lower grounds, even after making allowance for the possibility that permanent swamps in the sun might in some cases evaporate more than dense shady forests, will show that the net figures would have been so much on the writer's side as to invite criticism. It was also to avoid controversy on side issues that the writer assumed in his tables such high dry-weather run-off. But now, when his extra generous figures are being disputed, it is just that criticisms should be based on actual data according to the records, and corrected in conformity with the conditions which will exist when the lake is filled.

If Mr. Grunsky's figures were readjusted, as above, his available water, in a dry year like 1908, would be:

| | Cubic feet per second. | |
|---|---|---|
| All low-water inflow in lake, 4 dry months, in a year like 1908 | 800 | |
| Reduction, for reduced area | 100 | |
| | — | 700 |
| Water from lake storage (his figures) | | 2 210 |
| | | — 2 910 |
| To supply evaporation (his figures) | 1 140 | |
| To supply leakage at structures (his figures) | 250 | |
| To supply power, and other uses (his figures) | 200 | |
| For miscellaneous, accidents, and wastes | 0 | |
| For repairs, of gates, valves, machinery, etc. | 0 | |
| For lake forests, extra evaporation | 0 | |
| For consumption of population, agriculture, industry, etc., in the whole 1 320 sq. miles of basin and lake | 0 | |
| For losses on two spillways, on intermediate canal and on Lake Miraflores | 0 | |
| | — | 1 590 |
| Remaining for lockage | | 1 320 |

By the method of estimating used by the Board of Consulting Engineers and by General Abbot, full lockages should require 80 cu. ft. per sec., and, according to Mr. Grunsky's figures, the 1 320 cu. ft. per sec. will then permit only $\frac{1320}{80} = 16\frac{1}{2}$ lockages per day. This is on the extreme assumption of no losses from percolation, border evaporation, or any of the other items for which no allowances are made in that tabulation.

Mr. Sorzano.

The paper was intended to demonstrate that, with the rate at which it is claimed the Lock Canal could be operated, namely, "40 lockages up and 40 lockages down," the water supply will not be sufficient to maintain the draft necessary to pass that number of vessels, if, according to the plans now under execution, reliance for that service is placed only on Lake Gatun and on the 1 320 sq. miles of its immutable catchment basin, during the dry months of dry years.

The writer is much gratified with the fact that Mr. Grunsky, though disagreeing with him on some of the minor figures, not only does not controvert the main point at issue, but conclusively proves the writer's contention, as shown above.

*Full Lockages.*—In his calculations, the writer used full lockages, for the reasons stated in the paper. There is no existing authority to decide now the actual dimensions and number of vessels which may demand passage through the locks per day in the future.

The Canal is to serve forever. It is not being built with a guaranty that it will generally be idle, or that all the vessels will be small, or that 80% of them will be of some given dimension just small enough to suit the available supply of water.

Under the circumstances, perhaps it is not too sanguine for one who has seen the wonderful developments of the immediate past to believe that in time it will be necessary to use the locks at full lockages. This is the condition the writer ventured to assume. Who can prove that it is impossible or even improbable?

## Humidity.

Perhaps no one knows better than Mr. Grunsky that humidity data, as generally given, are incomplete and misleading, unless accompanied by the corresponding temperature data, not averaged, but taken simultaneously.

At first thought, it would seem—and it is generally believed—that a comparatively dry air, say for example at 70° Fahr., with 70% humidity, would be much more "thirsty"—or a better drier—than air at 80% or 90% humidity; and so it is; but only relatively, and not absolutely by quantity, when the temperatures are considered. To illustrate:

1 000 cu. ft. of air, at 70° Fahr. and 70% humidity,
will hold.....13 oz. of water.
1 000 cu. ft. of air, at 70° Fahr. and 90% humidity,
will hold.....17 " " "

But:

1 000 cu. ft. of air, at 90° Fahr. and 90% humidity,
will hold.....30½ " " "
And at saturation, at 90° Fahr., it will hold.....45½ " " "

Mr. Sorzano.

These figures show that, in the Canal Zone, say at 7 A. M., 1 000 cu. ft. of air at 70° Fahr. and 90% humidity (which would be considered very humid) can hold 17 oz. of water; but as soon as it receives the rays of the sun its temperature begins to rise. If it is raised to 90° Fahr., that air can hold 30½ oz. of water; and to reach the point at which evaporation would cease, it must absorb 45½ oz. of water. Now, as it happens that the more moisture there is in the air the lighter it becomes, this 90% humid air will be lighter, and rise rapidly in the atmosphere, and will be replaced by another volume of cooler air, and so on, as long as those conditions exist.

That is why prevailing fogs in the tropics, if intense between 4 and 7 A. M., lift so rapidly with sunrise, and disappear at about 8 A. M. during the dry season.

Even when there is no wind, this difference between the densities of these columns of air is sufficient to maintain the vertical currents, so important for evaporation; and yet they are never measured, estimated, or even mentioned by writers on the climate of the Canal Zone.

In many elaborate experiments now going on, in the United States, to ascertain evaporation, the degrees of humidity are measured in open pans placed at different heights, and tables are given showing the different strata of air, of variable humidity, beginning perhaps at 99% on the surface of a lake and decreasing as the elevation of the tanks is increased.

Such tables show the atmosphere as if it were composed of so many horizontal, superposed strata of air at different degrees of humidity, resting on each other, in equilibrium, and at rest, like so many volumes in a pile of books. And calculations are then made, on the figures given by the imaginary film of air just in contact with the water, at perhaps 99.99% humidity, and thus evaporation data are obtained.

In Nature such conditions do not exist, and cannot exist in the open air. Only in a closed bottle kept at an even temperature could such equilibrium be artificially maintained.

As long as the great canopy of the atmosphere remains open on top, under the sun's rays, the vertical air currents, due to these differences of temperature and density, will exist, either in the open or under the forests; and unless the intensity of these vertical currents (or the speed with which the air strata replace each other) is measured, such experiments are valueless.

These vertical air currents are not as easily measurable on a lake as in a chimney; but they exist, and when helped by the strong rays of the sun (so searching in the tropics), by the wind, by the constant fluctuations of the water's surface, and by the extra heat stored in semi-stagnant waters, the combined effect of these elements is considerable, as will soon be found out by those who attempt to store water in a reservoir with a wide surface, and rely on the humidity of the air to keep it in.

Mr. Sorzano.

It is also generally thought that great areas of water will necessarily create high permanent humidity. The preceding remarks in reference to vertical currents disprove that common error. If it were not so, the humidity in the middle of the great oceans, 1 000 miles from shore, would be at its maximum, which is not so.

There will certainly be more humidity in the air above a lake than above dry land or above an arid desert; but this only proves how active evaporation always is.

As far as the Canal Zone is concerned, the writer believes that the mean relative humidity—during the dry months of a dry year—will be somewhat less than the 84% named by the critics, on account of the topography of the region, the irregularity of the hills, and the constant breezes.

On the Isthmus, during 1908, the figures were:*

| | |
|---|---|
| Pacific Slope, year 1908, dry-season average | 77% |
| Bas Obispo (Chagres), dry-season average | 84% |
| Atlantic Slope, Cristobal, seashore, average | 80% |
| Average, in the shade | 80.33% |

The mean temperatures, in the sun, during the dry season, were:

| | | | |
|---|---|---|---|
| In January, | 1908 | | not given. |
| " February, | 1908, | maximum | 125° Fahr. |
| " March, | 1908, | " | 124° " |
| " April, | 1908, | " | 125° " |

With 80.33% sunshine.

The wind averaged from 27 132 to 45 175 miles, with frequent velocities of 37 and 40 miles per hour.

With such extremely favorable evaporating elements—wind and high temperature—humidity does not deter evaporation; it is caused by it.

*Fogs.*—In analyzing the criticisms in connection with the meteorological problems, the writer is much surprised to find that none of his critics has given any thought to the question of fogs; and yet it is one of the most serious problems for the Lock Canal, not only because it will diminish evaporation, but on account of the dangers of navigating some parts of Lake Gatun during dense fogs.

In that waterway, particularly between Buena Vista and Gamboa, in the submerged channels lying near islands and promontories, in short navigating legs, the angular, polygonal route is to be marked by "range lights, beacon lights, and buoys."

To negotiate such a polygonal route at night, in normal weather, demands well-trained pilots, familiar with the lights and the route, and well acquainted with the steering qualities of each craft. In the Culebra Cut, where the Canal will be of uniform and narrow width,

*Report, Isthmian Canal Commission, 1909, p. 191.

Mr. Sorzano.

and where the berms can be well lighted—like a street—with shores visible, even in the most intense fog, the sides can be easily followed by any sea captain knowing his own vessel, even if he cannot sight the beacons and range fires; but in the rest of the Lock Canal, on Lake Gatun (where the wider channels are to be marked by distant range lights), in case of dense fogs such beacons cannot be seen nor easily recognized. The channels being submerged, the legs short, the fires complicated—on account of the many zigzag angles—any small error as to distance and bearing will land the vessel on the shoals or against one of the rocks ahead, unless going at extremely slow speed. When finding their way by range lights, the tendency of pilots is to strike for the center lines; this brings all vessels in the middle of the channels, increasing the risks of head-on collisions.

The inconvenience and danger to navigation due to these conditions are so evident that the question would seem to need no amplification; and yet, when discussing it, the only answer received by the writer is: "Who has heard of dense fogs in the tropics?"

Generally, when Army engineers, doing Government work in the tropics, leave their quarters in the morning, the early rays of the sun have already been actively at work on the vertical air currents; the intensity of the fogs has disappeared. The pleasant mist is not noticeable then. That is probably why the Lock Canal engineers do not believe in fogs.

When an engineer is at the head of a sugar plantation where, during the dry season, work goes on day and night, he is soon brought to recognize the importance of fogs and their possible intensity.

Having traveled many miles on horseback at night in the tropics, the writer ventures to say that, even during the dry seasons, there will be many hours of fog that will inconvenience and endanger navigation in that part of the Canal near Buena Vista, Gamboa, etc.

Though not as dense as during the wet season, such fogs will nevertheless retard evaporation in proportion to their intensity and duration. In the paper a reduction of 11% was allowed for the effect of probable fogs on evaporation.

*Land and Foliage Condensation.*—Those who have read all that has been published on the Panama Canal up to the present time will not dispute the fact that these phenomena have never been mentioned before in connection with its meteorological problems.

*Land Condensation.*—When a soil is well "mulched" by plowing, scarification, etc., or is naturally "open" by porosity, evaporation cracks, fissures, etc., air has a facile access to its interstices and pores. During the day and the early part of the night the ground is hot, and continues warm for some hours after sunset. As long as its temperature is above that of the air, no condensation can take place. During the

rest of the night the soil gradually loses part of its stored heat, by radiation, evaporation, etc. If its temperature should get below the temperature of the atmosphere, the moisture in the air condenses and is absorbed by the soil. This land condensation penetrates the ground, more or less, depending on its physical conditions, its porosity, cracks, mulching, temperature, etc. Under favorable conditions, the moisture thus gained is considerable. Mr. Sorzano.

In this discussion this phenomenon is interesting, as it will reduce to a certain extent the losses by border evaporation and fly-off, but without, however, counteracting completely their effect, because it acts only during a few hours of the night, or rather early morning, the earth having had insufficient time to cool before the sun gets above the horizon again.

The beneficial effect of "land condensation" will not be felt on Lake Gatun, because the temperature of its waters will be at all times, day and night, greater than that of the air. Evaporation from its surface will never cease, even during the heaviest showers.

*Foliage Condensation.*—What happens between the air and the soil, takes place also, at night, between the air and the foliage of forests. Those who have attempted, in the tropics, to shake down from a tree some luscious fruit, in the morning, will recognize what the writer calls "foliage condensation"; perhaps "foliage shower bath" would be a better expression.

It was after having carefully considered these phenomena, that the writer figured only on 33 cu. ft. per sec. for border evaporation instead of the 150 or 200 cu. ft. per sec. which may be calculated, or the 100 cu. ft. per sec. which will probably take place.

If the calculations show such large border losses, it is because the border of the lake is so extensive—about 20 sq. miles.

If the bed of Lake Gatun was a regular basin, its border line would measure about 46 miles, but when full it will have a contour of more than 827 miles. As border evaporation is proportionate to the miles of beach, the large quantity obtained will be admitted.

It is interesting to note that Colonel Hodges has not thought of "land and foliage condensation" when trying to save water, and yet their effect is considerably more important than other items on which he has laid so much stress in his criticisms.

As for the evaporation data suggested by Mr. Grunsky, the writer does not approve of using for the Isthmus figures obtained in Massachusetts, or in any climate outside of the tropical zone.

The coefficients of evaporation named by the writer are based on the data published in the official records of the Isthmian Canal Commission for 1907-08, with the necessary corrections for sunshine temperature and for active lake surface, as explained in detail later.

Mr. Sorzano.

No doubt it will amaze the reader to learn that the evaporative data for the Canal Zone are obtained there now "in small tanks, 10 in. in diameter, protected from the direct rays of the sun." That is, not only by the crudest evaporimeter known—the small pan—but in the shade, probably at the comfortable temperature of 79° or 80° Fahr., and water from the faucet at perhaps 78° Fahr.

To form an idea of the inaccuracy of such an imperfect method, let it be remembered that the difference between shade and sunshine temperature in the tropics may vary from 30° to 40° Fahr.; that the semi-stagnant waters of Lake Gatun during the dry season, and conservatively quoted by the writer at about 90°, may really reach 114° Fahr. and more in the sun; that the combination of those aggravating elements may show a possible actual evaporation of more than 0.60 in. per day on a lake exposed to the sun, in a tropical climate, with days averaging more than 80% of actual sunshine, and with an almost continual breeze.

It must be remembered, also, that the actual evaporation on the lake is not equal to the evaporative data, or coefficient, but to the product of that coefficient by the active evaporative surface of the lake, which, as shown later, may be 10 or 12% more than the flat area of the lake as measured with a planimeter.

The writer will only say here that the percolation risk entered in his tables is not the seepage of water through the body of rocks, but the loss through fissures, seams, faults, crevices, etc., which may possibly exist in that vast lake basin under the still unexplored alluvial soil covering the greater part of that region, and now under luxuriant tropical vegetation.

If the amount, measured in cubic feet per second, is so large, it is because the outfiltering bed of the lake is so vast—more than 200 sq. miles.

The seepage tables, reproduced from the Report of the Isthmian Canal Commission, were given to emphasize this possibility of loss of water, for those who have not had the time to follow these questions very closely; and also to show how much larger are seepage losses in well-known cases, compared with the small coefficient of percolation suggested by the writer in his tables.

### Length of Dry Seasons.

Table 1 gives the rainfall for the fiscal year, 1907-08, from the official documents published by the Isthmian Canal Commission. These figures were taken because they were the latest, and possibly the most accurate at hand. That table shows that the dry season, that year, lasted 151 days; but, for the computations, only 120 days were considered. There is nothing in Table 1 misleading or indicating

anything else, and the writer is at a loss to know on what grounds Colonel Hodges can base his objection to it, except that it happens to give a dry year of record. Mr. Sorzano.

The writer firmly believes that when figuring on scarcity of water, it is wise to study the driest years, and the longest dry seasons, and not the averages of years of plenty.

Those who have had years of experience in the tropics, or have agricultural interests there, know very well that 120 days for a "dry season in a dry year" is a very conservative figure, as it is exceeded considerably every few years, and at too short intervals. A glance at the Isthmian records will prove it. The previous long dry season was in 1906, for the *Canal Record* says:

"In the previous dry year (1906) the dry season in Mount Hope Reservoir in the Canal Zone continued for 140 days." The preceding dry year was 1903, the driest on record, up to last year.

*Average Discharge in Dry Years.*—Colonel Hodges says the writer has overstated his case in saying that "the average discharge of all the streams that can empty * * * will rarely exceed 1 100 cu. ft. per sec. in dry years."

When Colonel Hodges quoted that general descriptive sentence he, inadvertently, did not notice the value of the last three words: "in dry years."

The complete sentence was:

"During the 3 to 5 months of 'dry weather,' the rains in that locality cease almost completely, and then the average discharge of all the streams that can empty into the proposed high-level lake at Gatun will rarely exceed 1 100 cu. ft. per sec. in dry years."

That the writer did not underestimate the dry months' run-off in dry years, will be admitted when it is known that the total discharge of all the streams above Gatun in 1908 did not reach 800 cu. ft. per sec.

Colonel Hodges also says: "The average in the worst known dry season for 19 years is 1 190 cu. ft. per sec." This is evidently leaving out 1907-08 when the discharge, according to the latest report (published in June, 1909) was 708 cu ft. per sec. for the 3 dry months. For, the official Report states:*

"The flow during the dry season of 1908 was lower than any other of record. During this period the average rate of discharge at Bohio for the three dry months (February, March, and April) was about one-half the normal for the years of record, the average rate of discharge for February of 681 cubic feet seconds, and for March of 586 cubic feet seconds being the lowest ever recorded. Previous to this record the lowest average rate of discharge for those months was 745 cubic feet seconds in 1903."

*Report, Isthmian Canal Commission, June, 1909, p. 182.

Mr. Sorzano.

The flow at Bohio being nine-tenths of the total flow available for Lake Gatun at Gatun, that rate will give for these months a dry-season run-off averaging only 703 cu. ft. per sec.

It is important to note here that the foregoing figures include all the inflows above Gatun; not only run-off from streams, and drainage, but all the direct rainfall on the lake, while, in the writer's tables, this precipitation on the lake, amounting to more than 100 cu. ft. per sec., is also credited to the lake, but under a separate heading.

The writer, to avoid discussion on the minimum run-off figures, while aware of those very low records, purposely assumed for his calculations a large run-off. A glance at the tables will show that he allowed for the 1st and 4th months of the dry season an accretion to the lake's level amounting to 0.3466 in. and 0.4810 in. per day for run-off only, equivalent to 1 271 and 1 300 cu. ft. per sec., respectively; and still more for the 3d and 4th months in Table 6. If to those amounts be added precipitation, it will be seen that the writer in his calculations—for the dry months of a dry year—figured on 1 370 to 1 400 cu. ft. per sec., considerably more than the amounts hitherto assumed by General Abbot and other authorities for those months in dry years.

This generous allowance was to cover any extra drainage run-off from the end of the wet season overlapping into the beginning of the dry season, to anticipate any claim of some possible premature extra large freshets at the end of the dry year, and particularly to avoid controversy.

Instead of overstating, the writer very carefully understated his case.

*Run-off in Average Dry Seasons.*—When studying problems of scarcity of water, figures of "years of plenty" and of "average years" have no value in the tropics. When Colonel Hodges has had 30 or more years' experience in tropical climates he will have more respect for the inevitable, ever-recurring dry years, which come at short intervals to exhaust reservoirs, reduce crops, destroy vegetation, and —evaporate dividends.

## Evaporation Data.

The coefficients suggested in the paper have been so misunderstood, and the matter is so important, that a complete analysis of the subject may not be amiss here; for it is a remarkable fact that, after 6 years of American work on the Isthmus, the critics, in controverting the writer's evaporation figures, have no other data to offer than those obtained in the United States, in Nicaragua, or on the Isthmus, "in the shade," by the crudest known method.

This will perhaps explain the divergence of opinions on the subject. Mr. Sorzano.

*Initial Evaporation.*—The writer believes that the 6.026 in. of evaporation per month (0.197 per in. per day) mentioned by Colonel Hodges, is insufficient for actual loss on a lake in the tropics during the dry season.

That amount may possibly be the showing of evaporating pans under peculiar conditions, but it cannot be the actual dry months' evaporation on the ever-agitated surface of a warm-water lake exposed to the sun's rays in the tropics, with the increased active evaporative surface due to ripples and waves, the action of the wind, etc., and with large forests standing in it.

The low evaporation rate given by Colonel Hodges is perhaps due to the amazing fact that the data on which he bases his opinion are obtained on the Isthmus "from insulated tanks, 10 in. in diameter and 3 ft. deep, exposed to all atmospheric conditions except the direct rays of the sun."

The writer has measured, in the tropics, the actual evaporation from large masonry tanks, under meteorological conditions almost identical with those of the Canal Zone. The actual loss in the open has always been more than 6.026 in. per month for the dry season of dry years. It is true that his experiments were not conducted with the action of the sun's rays left out. Inasmuch as Lake Gatun will be in the open, and will have an immense area exposed to the direct, almost vertical, rays of the sun (9° N. latitude), at 85 ft. elevation, in close proximity to the ocean, and subject to its constant breezes, the writer is amazed at the low coefficient of evaporation advocated by Colonel Hodges and others, particularly when it is considered that the measurements taken at Ancon and at Cristobal—even in tanks protected from the rays of the sun—have actually shown, according to official data published in the *Canal Record,* the rates given in Table 20.

TABLE 20.—DAILY EVAPORATION ON THE ISTHMUS, IN THE SHADE.

| | | | | | |
|---|---|---|---|---|---|
| February, | 1908, at Ancon | 6.557 in. | Average, | 7.2580 = 0.2500 in. per day. | |
| " | 1908, " Cristobal | 7.959 " | | | |
| March, | 1908, " Ancon | 6.997 " | " | 7.2760 = 0.2347 " | " |
| " | 1908, " Cristobal | 7.557 " | | | |
| April,* | 1908, " Ancon | 5.921 " | " | 6.4255 = 0.2142 " | " |
| " | 1908, " Cristobal | 6.930 " | | | |
| Giving a mean average of | | | | 6.986 = 0.2330 " | " |

*In April, 1898, the evaporation was 8.130 in., or 0.2710 in. per day.

When preparing the paper the writer endeavored to use only official data published in the Canal documents for the year under analysis—

Mr. Sorzano.

the fiscal year, 1907-08—and, to avoid controversy, he took the figures in Table 20 as a basis for his calculations.

The averages for the whole year, or for the wet season, mentioned by Colonel Hodges, obviously have no place here, as this discussion relates only to evaporation during the dry months. The rainfall during the wet season exceeds the loss by evaporation.

*Correction of Initial Data.*—The 0.2330 in. per day measured in the 10-in. tanks in the shade may be considered to represent the "still water" evaporation, at the mean temperature of that locality, in the shade, with fresh water perhaps at 78° Fahr. or less.

As Lake Gatun will be in the open, and exposed to the searching rays of the tropical sun, the evaporative conditions will obviously be at higher temperatures than in the experimental tanks, in the shade. The calculations, to be accurate, must be based on "sunshine data." As these have not been measured on the Isthmus, and in consequence are unobtainable, one is compelled to compute them by any other data available.

The result will depend principally on two important features, which have never been considered in previous studies of this problem on the Isthmus, namely:

*A.*—The net unit of evaporation per square foot of surface, due to temperature of the air, temperature of the water, velocity of the wind, total sunlight, hygrometric degree, barometric pressure, etc., etc.

*B.*—The active evaporative area of the lake, or actual surface of contact between air and water, and on which evaporation takes place.

*A.—Unit of Evaporation.*—

This rate of evaporation depends on various factors, among which the more important are:

*I.—Effect of Temperature of Air.*—The maximum temperatures on the Isthmus, in the sun, according to the *Canal Record* for 1908, were as follows:

| | |
|---|---|
| January ..... | not given. |
| February, maximum ..... | 125° Fahr. |
| March " ..... | 124° " |
| April " ..... | 125° " |
| Averaging, say ..... | 124° " |
| The percentage of sunshine (dry season) was .... | 84% |
| Humidity, same year (average dry season) " .... | 78% |
| Average wind movement, same year (dry season) | 29 600 |
| Maximum velocity of wind ..... | 40 miles per hour |

From these data the probable mean temperature of the air in the sun may be computed approximately as follows:

| | | | | | |
|---|---|---|---|---|---|
| Assuming | 3 | hours | at ..... | 124° | (hottest sun), |
| " | 4 | " | " ..... | 120° | (medium sun), |
| " | 3 | " | " ..... | 96° | (usual sun), |

gives for the 10 hot hours a mean temperature of about 114° Fahr. This may seem high, but the following counter analysis proves that it is about right, and on the safe side: Mr. Sorzano.

| | | | |
|---|---|---|---|
| Assuming | 4 night hours, averaging | ..... | 75° |
| " | 10 " " " | ..... | 79° |
| " | 10 sunlight hours, as above | ..... | 114° |

gives a hot-weather average of 92.92° Fahr.; and a night temperature of 78° Fahr., and these are about the figures for that locality in that season of a dry year.*

This 114° is not the temperature that a perspiring man, in motion, will feel; but the heat to which an inanimate object, a thermometer, a boulder, or Lake Gatun, will be subjected.

Assuming these figures, the thermal conditions of evaporation per day will be:

14 hours averaging, say, 78° shade and night,
10 " " " 114° sunshine.

Neglecting the shade hours—by assuming them to be of about the same temperature as those at which the measurements are now taken in the shade on the Isthmus—gives during the dry season, every day, 10 hours of "scorching" sunshine, averaging 114° Fahr., or a thermal difference of 36° Fahr. for sunshine hours only.

To avoid controversy in reference to these calculated figures, and to allow for the few rains that may have fallen during the alloted sunshine hours, the writer assumed a thermal difference of only 30°, instead of 36° (16.66% reduction). Now, the results obtained by Mr. Samuel Fortier, the very able meteorologist of the United States Government, show that an increase of 10° Fahr. will increase evaporation from water surfaces at the rate of 0.1428 in. per day.

Taking those figures, instead of the data obtained by the writer, and considering only the 10 day-hours instead of 24 hours, will give 0.0595 in. per 10 hours for every 10° difference of temperature, or $0.0595 \times 3 = 0.1785$ in. to be added per day to the original evaporation data as now measured on the Isthmus in the shade. The result will be:

| | |
|---|---|
| Original Isthmian figures, in the shade..... | 0.2330 in. |
| Add for difference due to sunshine..... | 0.1785 " |
| Sunshine, flat evaporation, per day..... | 0.4115 in., |

all other conditions having remained unchanged.

*II.—Effect Due to Higher Temperature of Water.*—Lake Gatun, during the dry season, will gradually, but rapidly, acquire a comparatively high surface temperature, due to the following cumulative conditions:

*All these computations would be unnecessary if accurate data were taken on the Isthmus, with modern, self-registering instruments. Such instruments are on the market and ought to be used on the Isthmus.

Mr. Sorzano.

*a.—The Large Land Area of the Lake Bed.*—This, in the shallow parts, will absorb the sun's heat during the day and give it back to the water during the day and night. The exceptionally corrugated condition of that bed, the extraordinary number of ravines and the 1 300 peninsulas, add immensely to its actual land area, not only as to absorption and storage of heat, but, so to speak, as to its vast "heating surface." For many square miles, the water will be—after the first days of the dry season—almost stagnant, with no more circulation than will be produced by evaporation on its borders, or by the fly-off from the trees. Even the cooling effect of the shading trees will be counteracted by the higher temperature due to the fermentation of dead leaves and detritus from such trees. Such aggravating features will inevitably contribute to a gradual increase of temperature, and this will soon bring the lake to the sunshine heat if it is not mitigated by an excessive surface evaporation. (Loss of water through the trees by fly-off, does not cool the lake surface.)

*b.—Large Masses of Warm Water.*—Lake Gatun at Elevation +80 will hold from 150 000 000 000 to 160 000 000 000 cu. ft. of water, which will be at about 90° Fahr. in the beginning of the dry season. Were it not for evaporation, it would very soon reach 114°, due to the new heat received every day from the tropical sun.

During the dry months the daily volume of incoming fresh water is so small compared with the 160 000 000 000 cu. ft. of stored warm water, that it cannot refresh more than a very small portion of the lake. As one-half of the daily consumption of the locks must be delivered at opposite ends of the lake, and as all the water coming from the Upper Chagres will run directly toward the Pedro Miguel locks at Gamboa, without even entering the lake proper, its cooling effect will be lost, as it will go where the waterway is the narrowest, and the evaporative surface the smallest.

*c.—Vessels in the Lake.*—With 40 lockages up and 40 lockages down, claimed as the capacity of the Canal, the lake will have at all times a large number of vessels in transit. There must also be considered the effect of all other lake craft, the large steam power-houses at Gatun—in operation during the dry season—and any and all industrial steam plants that may locate on the shores of that lake, or in its inland harbor. With the high initial temperature of the lake water, the condensers of all these steam centers will heat and reheat millions of cubic feet of the lake water to 130°, 150° and even higher temperatures.

The combination of all these and other features will not only gradually heat the water, but contribute to keep it at a considerably higher temperature than would prevail if there were only normal causes in operation; it will be higher than the average temperature of the air, thus preventing night condensation; and, of course, it will

be higher than the temperature of the always fresh, cool water in the evaporating tanks where data are now obtained in the shade. Mr. Sorzano.

The writer, however, will not use here any of these possible or probable maximum figures. It will only be assumed that, due to excessive evaporation, the top layer of water on the lake remains at 98° Fahr. Even this will give a thermal difference of 20° between the lake and the evaporating tanks.

According to Fortier's very interesting experiments, 0.01 in. of evaporation per day may be added for every degree of increase in the temperature of the water. If such data are accepted, 0.20 in. per day would have to be added to the rate already found.

These two thermal influences will bring the coefficient of warm-water evaporation in the open to $0.4115 + 0.2000 = 0.6115$ in. per day for warm-water evaporation in the sun, neglecting all other influences.

The writer, however, did not use that figure. To allow for any hours of fog, which on certain occasions may extend into the day hours; for the cooling effect of some local rainfall on the lake; for the extra shade on the shady sides of some of the islands and shores, or in the extra dense lake forests; and, to keep on the generous side of the calculations, he cut the above rate in two. This 50% rebate still leaves a daily evaporation of 0.3057 in.

Even this minimum reduced rate is larger than the 0.27 in. suggested by the writer as a probable evaporation unit for Lake Gatun.

The second factor to consider now is the active evaporative surface of the lake, an element never before analyzed by other writers on the Panama Canal.

*B.—Actual Lake Surface.*—In Lake Gatun the actual, active evaporating surface of the agitated water in contact with the absorbing air—which is the surface where evaporation takes place—will be, as explained elsewhere, considerably larger than the 165 sq. miles of flat surface measured by Colonel Hodges on the map by the lake's contour.

This increase of area is due: First, to the additional surface developed by ripples, waves, white-caps, spray, etc., caused by the wind, the churning of wheels and propellers, or by any other disturbance of the water; and, secondly, by the increased wet area around the bark of trees and vines standing in the lake, due to such oscillations of the level and to capillarity.

The writer will not inflict on the reader even an approximate calculation of this additional area on Lake Gatun. It will perhaps suffice to state that the gentlest ripples on a lake correspond to a 2% increase of surface; that a spray reducing 1 lb. of water to globules $\frac{1}{16}$ in. in diameter increases the surface in contact with the air 240 times; and that the wet trunk of a tree only 4 in. in diameter will

Mr. Sorzano.

expose to the air from 15 to 20 times more water surface than the area the same stump occupies in the lake.

These, at first, may seem to be very small matters, but there are, for instance, more than 450 000 000 trees, of 4 in. diameter and less, in 80 sq. miles of tropical forest of average density. This item alone would increase the area of the lake by 16 sq. miles, or 10% of its original flat surface—not by fly-off, but by actual increase of surface. The passing of steamers will disturb and churn, not 1 lb. of water, but tons of it.

Under such circumstances, it is reasonable to admit that these two elements alone will increase the active surface of Lake Gatun from 10 to 15%, giving it from 180 to 240 sq. miles of "actual evaporative surface," instead of the 165 sq. miles on which Colonel Hodges and others insist on figuring.

*True Rate of Evaporation.*—Combining the thermal rate with the surface factor, gives:

| | Inches. | Cubic feet per second. |
|---|---|---|
| For a 10% increase $\left(\frac{180 \times 0.30}{165}\right)$ | $= 0.3272$ | $= 1\,452$ |
| " " 12% " | $= 0.3636$ | $= 1\,614$ |
| " " 15% " | $= 0.4364$ | $= 1\,938$ |

This shows that the 0.2712 in., entered in the tables, is not only possible but very conservative indeed, particularly if it is remembered that in these computations the action of the wind has been neglected, assuming that it had been somewhat felt in the 10-in. pans, though such small pans do not gauge well the effect of the wind, unless they are refilled often, to keep the level of the water near the edge.

To show that the foregoing seemingly high figures are not beyond possibility, the writer (though reluctant about using the figures of one locality for another), believes that Table 21 will be interesting to those who have not had occasion to measure evaporation.

TABLE 21.—EVAPORATION IN CULIACÁN (MEXICO).*

| | In the shade. | In the open. |
|---|---|---|
| Mean evaporation, in 24 hours; April, 1909; average sunlight, 7.36 hours per day; average wind velocity, 6.10 miles per hour; average temperature, 24.01° cent. (75.21° Fahr.) | 0.2555 in. | 0.451 in. |
| Maximum evaporation in 24 hours; April 22d, 1909; 9 hours sunlight | 0.351 " | 0.680 "† |
| Total evaporation during April, 1909; 221 hours of sunshine; average temperature in the shade, 23.85° cent. (74.93° Fahr.); maximum temperature in the open, 38.12° cent. (100.61° Fahr.); the month was "cloudy." | 8.26 " | 14.16 " |

The evaporation in the open was 71% more than in the shade, as an average for the month

* The completeness of the data recorded by the able Director of the Meteorological Station at Culiacán indicates what might be done by our engineers on the Isthmus.

† Showing that the evaporation in the sun is 91% greater than in the shade.

Mr. Sorzano.

The foregoing tedious analysis shows that the differences between the writer and his critics, on this important question, are:

Colonel Hodges figured on the evaporation of calm, cool water, on a flat lake, without any allowance for local conditions.

The writer figured on the actual loss of water, due to the increased area of the lake, and to the true evaporation rate as corrected for open-air conditions and higher temperatures.

The reader will judge who is on the safer side.

### Lake Forests.

*Area.*—Assuming waves only 1 ft. high; a capillarity of 4 ft., and trees with roots not more than 5 ft. deep, the plane of lake moisture will be felt at Elevation +95. At that reference the flat water surface of the lake is 180 sq. miles. With trees only 35 ft. high in the valley and 15 ft. on the crests, the ground on which they must stand so as to reach 5 ft. above water, is at Elevation +55, where the lake has an area of 105 sq. miles. These conditions will give 75 sq. miles of forests with the trees not less than 5 ft. above water, at mean +85 level.

With taller trees and the lake below +85, the forest area will be considerably larger. With the 1 300 promontories in that lake border, the action of capillarity will be felt at considerably greater height than 4 ft., and the actual land area of the bed will also be very much larger. These increases will be waived here, to make up for bare spots, etc., leaving the 75 sq. miles of lake forest—a conservative net figure.

By the very irregular configuration of that basin and the great inclination of the ground, the trees will be on inclined planes with their foliage at different heights. This will permit better circulation of the air currents and cause more evaporation and fly-off than if the forests were on a level, with trees all of the same height.

*Foliage.*—In northern climates, trees (except evergreens) get their leaves in the spring and drop them in the fall. Defoliation takes place in a different manner in the tropics. Trees that seem to be evergreen are continuously getting new leaves and dropping dead ones. In general, every 28 days some old leaves are lost, and some new ones gained. A few plants make a clear job of it in the dry season, but the great majority are subject to astronomical influences, among which that of the moon predominates.

These 75 sq. miles of forests will be not only continually absorbing water from the lake, but forever dropping dead leaves—a perennial source of detritus for the $\frac{1}{32}$ in. of play around the valves, gates, and screens in the locks, on which Colonel Hodges figures, and for the spillways.

The rest of the submerged forests also will be a continuous source of danger to propellers of passing craft.

*Sanitary.*—The United States has spent more than $30 000 000 in the sanitation of the Canal Zone and in destroying all breeding places

Mr. Sorzano.

of mosquitoes. Many more millions are now being spent in creating a lake which will have not only 827 miles of shore line, but 20 miles of saturated border lands, and more than 80 sq. miles of semi-stagnant forest lakes, where the *Anopheles* and the *Stegomyia* will be beyond the most energetic and intelligent efforts of Colonel Gorgas. Unless these forests are cut down, and the borders cleared and kept cleared, it will be impossible to continue on that lake the admirable system of sanitation established so successfully by that eminent hygienist. And if the tsetse-fly should ever find its way to that border line, the consequences would be appalling.

*Cost of Cutting the Forests.*—In Cuba, with laborers at $1.25 (gold) per day, it costs from $27 to $53 per acre to cut, burn, and clear light forests, and from $50 to $125 per acre for heavier ones. In Panama such light work will cost from $35 to $70 per acre. The lots at a distance, quite inaccessible or dense, will cost from $75 to $200 per acre. As what remains in that basin is probably the most difficult part, it is not likely that the average cost would be less than $75 per acre. At that rate it will cost $7 500 000 to clear once, the land for Lake Gatun. That will be the cost of preventing fly-off.

As for the subsequent annual expenses of cutting and burning the grass and new vegetation on the 20 or more sq. miles of borders, and the necessary filling of crab holes, etc., they are beyond approximate computation. The cost will depend on the number of cuts, and will be high, as the work cannot be done by machinery. Good results could be obtained by the grazing of 28 000 cattle and 4 000 goats; but Colonel Hodges might object to the quantity of water they would use from the lake. The cattle would also increase the supply of mosquitoes and flies.

*Fly-off.*—The writer cannot very well be said to have overlooked the question of fly-off, as he is the first one to have considered—or at least mentioned—fly-off and border evaporation in connection with Lake Gatun problems. He is much gratified, though, to note that Colonel Hodges now alludes to the "tremendous amount of moisture" lost in that way.

Moist lands, either bare or covered with vegetation, lose, indeed, every day quite a large quantity of water by the combined effect of fly-off and land evaporation. The loss will vary with the kind and condition of the soil, the class of plants, the degree of saturation, the temperature of the air and water, the slope of the ground, the season, the prevalence of air currents, etc., etc.

Under favorable conditions, the daily loss may be two or three times the loss that would take place from the surface of the water under the same conditions.

Mr. Fortier, after some very interesting experiments, has found evaporation from saturated soil to be 0.6785 in. per day, when the

water surface evaporation was only 0.26857 in.; an increase of 2.532 times. Mr. Sorzano.

This was under the following conditions:

| | | |
|---|---|---|
| Temperature of air in the shade | 71° | Fahr. |
| " " soil in shade | 76° | " |
| " " surface of water | 77° | " |
| " " moist soil in the sun | 83° | " |
| " " soil in the sun | 95° | " |
| Bare soil, evaporation, per day | 0.6785 | in. |
| When water surface evaporation was | 0.26857 | " |

This shows a land evaporation of, say, 0.68 in., for air at 71° to 95° and water at 77 degrees. The loss will certainly be much more at the higher sun and water temperatures recorded on the Isthmus.

Neither did the writer overlook the loss that takes place now from the lands which will be inundated by Lake Gatun. When establishing that lake's budget, he considered that and the following elements:

*I.*—That the deeper part of the lake bed, near Gatun, is already somewhat cleared or more open, with fewer high trees, but with many marshy spots and swamps where active evaporation and fly-off take place now.

*II.*—That the rest of the basin is at a higher reference, and covered with denser forests, from which—after the dry season is well on its way—less evaporation per unit of area takes place now than in the swamps or in the same forests when they are standing in water in the lake.

*III.*—That, after the lake is filled, not less than 75 sq. miles of these forests will stand in the lake, on sloping ground, with their roots in water and the foliage at different heights above it, and under the searching rays of the sun—ideal conditions for maximum fly-off.

*IV.*—That the unit loss per sq. mile from these lake forests will be considerably more when standing in water—after the lake is filled—than it was from the same areas before, on account of the reduced fly-off from dry forests, on dry soils, during the dry season.

*V.*—That the water of Lake Gatun when in service will be warmer than the water in the swamps now, and warmer than the atmosphere, which will eliminate the condensation gains at night.

*VI.*—That the area of the lake forests is several times larger than the total area of the swamps that will be covered, and the lake will lose more by the forests than it gains by the swamps, even if it could be proved that the fly-off of the densest forest were only a fraction of the loss from the most effective swamp.

If all these matters had been stated in the paper it would have been made unreadable; and, as a balance sheet under the above assumptions would have shown a very large net loss on the lake, and in con-

Mr. Sorzano.

sequence would have favored the writer's contention too much, he abandoned fly-off to "miscellaneous, etc.," and gave his figures for border evaporation only, in order to invite criticism on that new subject.

The writer abandoned, also, to "miscellaneous, etc.," another important item, one to which Colonel Hodges has not given a place in his criticisms, namely, the reduction of dry-season run-off.

## The Reduction of Dry-Season Run-off.

The total catchment basin for all the tributaries of the future lake, is given in the Report of the Isthmian Canal Commission as 1 200 sq. miles. The writer, remembering the impossibility of surveying accurately crest lines through tropical forests, adds 10% to that area, making it 1 320 sq. miles.

The 165 sq. miles occupied by the lake when filled up to the 85-ft. level will not be added to that basin, but taken from it, and inundated.

If one could imagine the catchment basin to have the same storage capacity all over its surface, the dry-season run-off from it would be proportionate to the area. Deducting 165 from the 1 320 sq. miles in the basin would reduce the dry-season run-off in the same proportion, or 12½%; but the alluvial soil—where the water is stored and from which the dry months' seepage run-off comes—is known to be considerably thicker below reference +85 than at the higher planes and on the rocky hills. The rainfall, also, is more copious in the lower basin near Gatun than in any other parts of the central region.* These two conditions assure a larger storage capacity for the lower strata, and in consequence a larger run-off from it; therefore, the actual loss will be considerably more than in proportion to the areas. This difference, however, will be waived, or rather left to counterbalance any better run-off that may be produced by the small slice between +85 and +80, which will drain when the lake is lowered, and for good measure.

Assuming, then, only a *pro rata* shrinkage, dry-season inflow to the lake would be reduced as follows:

In a dry year showing 1 200 cu. ft. per sec., 12½% = 150 cu. ft. per sec.

In a dry year showing 1 190 cu. ft. per sec., 12½% = 148 cu. ft. per sec.

In a dry year showing 1 100 cu. ft. per sec., 12½% = 137 cu. ft. per sec.

In a year like 1908, 800 cu. ft. per sec., 12½% = 100 cu. ft. per sec.

---

*Results of 33 years' observations at Colon:
Dry-season rainfall, Atlantic side, per month = 3.70 in.
Dry-season rainfall, in the interior, per month = 1.56 in.

Mr. Sorzano.

The writer believes the foregoing amounts to be too low, for the following reasons:

*a.*—The alluvial soil in the valley below +85 is several times thicker than on the hills and the higher slopes; and the storage capacity and consequent run-off will be in proportion.

*b.*—The changes in the hydraulic gradients will create disadvantageous conditions; for instance, some of the seepage drainage flowing now at +5 or +10 elevation, will meet a head of 85 ft.; the drainage from the higher planes, on the contrary, will have a shorter distance to run to reach the lake, and will discharge more quickly.

*c.*—It can be conceived that, under these conditions, after the last rain of the wet season has fallen, the run-off from the hills above +85 will be more rapid, and perhaps too rapid, emptying into the lake when water is still running over the spillways, and exhausting the thin layers on the hills when the water cannot be stored.

After the first month of dry weather the run-off, on the contrary, will be much reduced, due to that condition.

*d.*—The total result will be an actual loss to the lake much larger than calculated by the *pro rata* area method.

Under the circumstances, it would seem that the safe figures would be at least 150 cu. ft. per sec. for a year like 1908.

As there are no melting snows, and no storage lakes in that basin to make up for this certain loss, it is inevitable and irreparable. And yet this important loss has not been considered at all, nor allowed for by Colonel Hodges when objecting to other minor losses of much less importance entered in the tables.

### Border Evaporation.

Colonel Hodges evidently confuses border evaporation with fly-off; but his admission, that they give off a "tremendous amount of moisture," shows that he instinctively perceives their importance. The writer, however, would have preferred to have him give more definite data for discussion, than that otherwise very appropriate adjective, "tremendous."

By border evaporation is meant the loss which takes place from the moist lands all around the lake, the water being furnished by the lake, either by capillarity, by saturation, or by direct watering due to waves or other oscillations of the water level.

The shore, from which such border evaporation will take place, can be considered in two parts:

*A.*—The inside beach, on the whole periphery of the lake, kept constantly saturated by the incessant fluctuations of the water, due to waves, wind, lowering of the lake, etc., etc.

*B.*—The outside beach, farther out, kept moist only by capillary

Mr. Sorzano.

movement of the water through the moist soil, all around the inside beach.

*A.—Inside Beach or Border.*—The total length of the lake's contour line, neglecting small coves, is 827 miles. The width of the inside strip which will be watered by the lake fluctuations, will vary considerably, according to the irregularities of the ground, and the magnitude of the oscillations.

Leaving out exceptionally stormy weather, the width of the watered strip may vary from 1 ft. in the vertical walls to 100 ft. or more on the flat slopes. At the same ratio at which the contour lines spread on that basin, fluctuations of 1 ft. in the water level will cover and uncover 17.54 sq. miles of moist land; to facilitate calculations, say, only 16.5 sq. miles.

Instead of the tremendous evaporation suggested by Colonel Hodges, instead of the figures found by Fernow, or the 0.68 in. by Fortier, or any of the higher rates found by other investigators for saturated soils under high thermal conditions, the writer takes only the 0.30 in. found for Lake Gatun. The 16.5 sq. miles of inside border will receive every day from the lake and evaporate at the rate of 110 cu. ft. per sec. for inside border evaporation only.

*B.—Outside Beach or Border.*—Assuming a strip only 21 ft. wide, kept moist by drainage, run-off from uncovered storage, and by capillarity, there will be, on the outside border, a moist land area of 3.40 sq. miles. There are on the serrated contour of the lake and islands more than 1 300 narrow peninsulas in which the two opposite sides are so near that capillarity will act all the way across them. This will add considerably to the above area, but it is here waived to make up for extra shady spots, and for good measure.

Usual soil will allow a capillary movement of more than 2 lb. of water per square foot in 24 hours, or about 10 cu. ft. per sec. per sq. mile.

Limiting the figures to what that rate of capillarity will permit, under usual conditions, there will be, on this outside border, a loss of 34 cu. ft. per sec.

The total of these two items will give a daily loss of 144 cu. ft. per sec.

The writer, to avoid controversy on side issues, entered in his tables a loss of only 33 cu. ft. per sec. The true amount will evidently be many times larger.

*Land Area of the Lake Bed.*—When computing border evaporation one has to consider the "land area" only, and not the surface of the lake.

Colonel Hodges, when quoting the writer's phrase, "in every dry season, will uncover an area of land measuring more than 100 sq. miles," did not pay due attention to the word "land," and conse-

quently entered into an unnecessary and quite irrelevant discussion on the extension of the lake surface. The land area specified so plainly by the writer in the above requoted sentence is the actual, undulating, irregular, geological surface of the ground itself, not as it would be measured on a map; not the flat surface of the lake; but as in actual contact with the air. This land area, of course, is considerably larger than the flat surface of the lake as measured by Colonel Hodges between contour lines. Mr. Sorzano.

In the case of the Gatun Basin, the corrugations of the ground are so numerous and deep, that the increase in area is considerably more than usual, as will be noticed by a glance at the extraordinarily serrated contours of the lake, shown on Plate VI.

If the Gatun Basin were a hemispherical bowl, the lake would have a circumference of only 45.84 miles; as it is, the lake has a periphery measuring more than 827 miles. This explains the increased "area on land" stated by the writer.

*Peculiarities of Lake Gatun.*—Attention is called to the following features of Lake Gatun, as shown on the map, Plate VI:

1.—The extremely serrated contour line, showing the great corrugation of the bed, thus increasing the land area of the basin.

2.—The multitude of large and small peninsulas, which by capillarity will be water-saturated, thus increasing border evaporation and fly-off.

3.—The multitude of large and small bays, where water will be very warm and absolutely stagnant during the dry season, thus increasing evaporation.

4.—The close proximity of the water edge to the crest line of the drainage basin, or the water-shed, which may facilitate seepage at the points, *M, N, O, P,* and *G.*

5.—The polygonal route of navigation and the submerged channel, *A-B-C-D-E-F-G-H,* through the irregular sections of the lake.

6.—The proximity of that submerged channel to the land, and to promontories and islands, particularly at *B, C, D, E,* and *F.* Any error in the bearing may ground a vessel on the submerged promontories indicated by the serrated contour line.

7.—This map shows the water at Elevation +85; at lower elevations the submerged obstacles will be closer to the route of navigation, though invisible above water. From *A* to *H* the submerged channel is excavated through these obstacles.

8.—The entry of the Chagres River at Gamboa, running into the Lock Canal at an angle of 80 degrees. As no provision is made for the control of this river during the wet season and during freshets, the fact that it will empty its enormous flow directly into the Canal will endanger vessels navigating between *F* and *G.*

Mr. Sorzano.

9.—The sediment carried by the Chagres River will deposit irregularly between *C* and *G*.

10.—The most dangerous part of the submerged polygonal route, between *A* and *G*, is also the part of the Canal where intense fogs will prevail in the early morning, or from 1 A. M. to about 7 A. M., particularly in the wet season—when the fogs may last from midnight to 8 A. M.

11.—In navigating a polygonal route, pilots, to find their bearings, have to get on the center line—to be in line with the beacons. When two vessels going in opposite directions attempt that—on a short leg—head-on collisions are not impossible.

12.—In a sea-level canal, there would be no submerged channel in that region, the canal being cut through the ground with the shore always visible. The vessels would not have to get their bearings from distant lights; they would follow the shore, keeping to the right, with no possibility of collision.

13.—Attention is called to the very irregular width of the tortuous gorge through which the submerged channel, *A, B, C, D, E, F, G*, winds its way through that part of the canal, between hills, islands, and promontories. This irregularity of the channel will cause eddies and currents of different velocity, ever varying with the depth of the water and the flow of the rivers in different seasons, and during freshets. The régime of that navigating channel will always be varying with these changing conditions.

## Percolation.

The facts on which the writer based his assumption that there was a risk of a certain amount of percolation in Lake Gatun, are as follows:

*I.*—A lake bed measuring considerably more than 200 sq. miles, the greatest part of it still unexplored, covered with its natural growth of tropical forests, and substrata conditions as to fissures, faults, crevices, seams, etc., unknown at the time the paper was written, and investigations, borings, etc., still going on.

*II.*—Experiments, borings, etc., wherever made, have shown pervious materials, and in some places well-defined joint planes and seams through which water passes freely with velocity enough to throw the stream from 1 ft. to 1½ ft. into the opening.*

In other places:

"Some of the rocks are of open texture and permit the flow of water."†

These quotations are from the official Report of the engineer in charge of the investigation of the lake basin.

*Report, Isthmian Canal Commission, 1908, p. 165.

†*Loc. cit.*, p. 127.

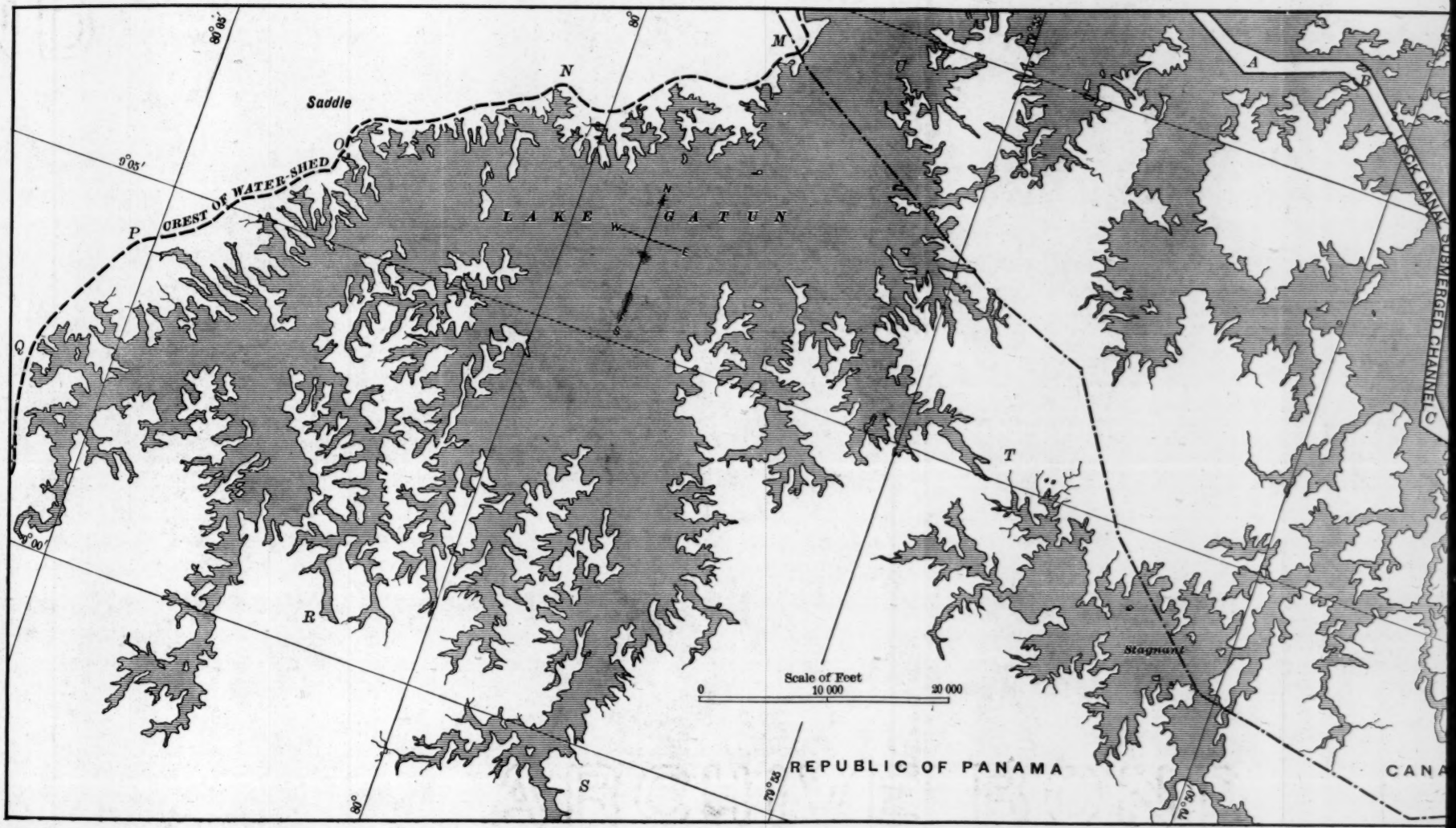
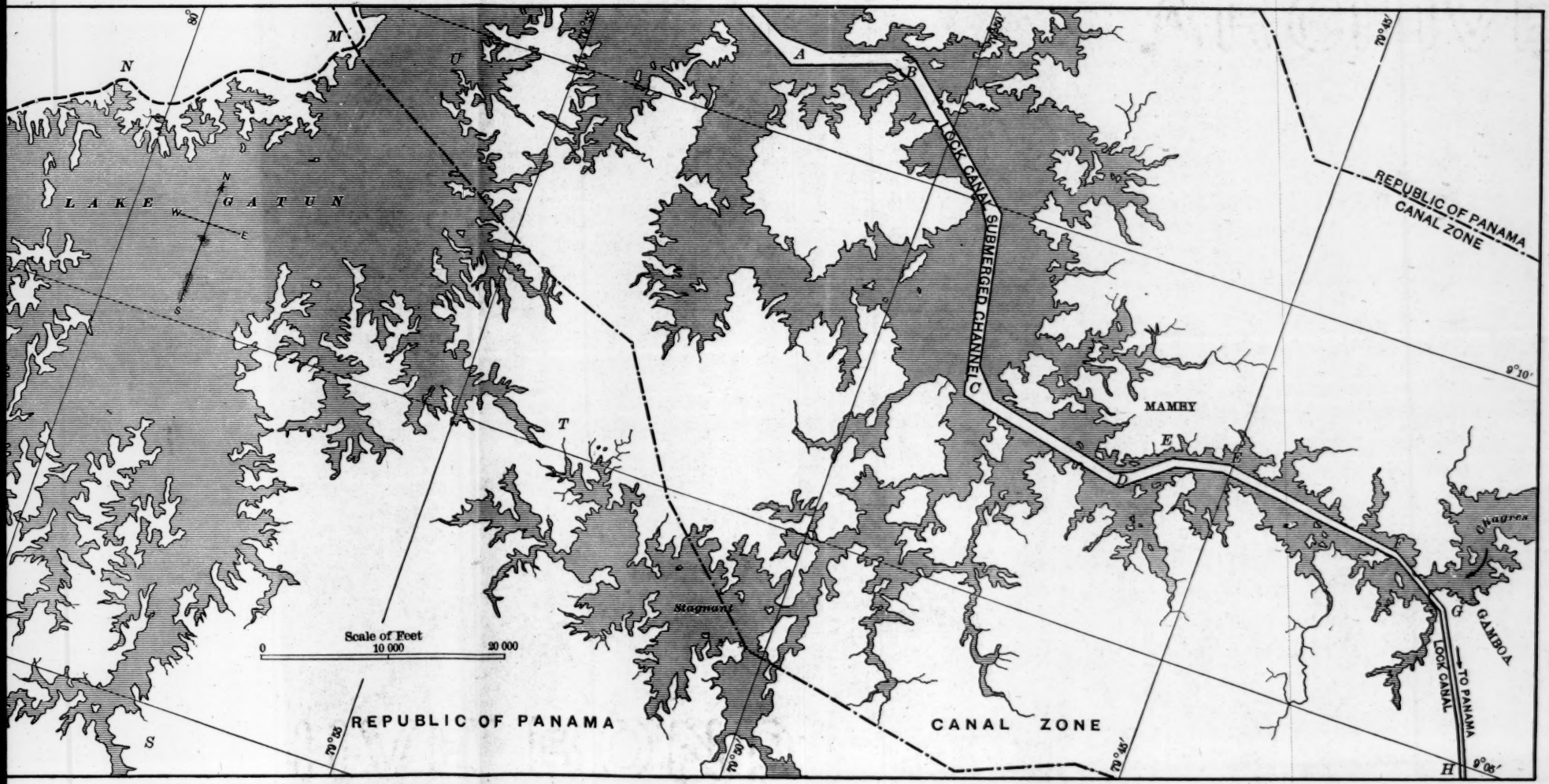

Saddle
CREST OF WATER-SHED
LAKE GATUN
N
W
E
S
Scale of Feet
10 000
0
20 000
Stagnant
REPUBLIC OF PANAMA
LOCK CANAL SUBMERGED CHANNEL
9°05'
9°00'
80°05'
80°
79°55'
79°50'
M
N
O
P
Q
R
S
T
U
A
B
C

PLATE VI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1145.
SORZANO ON
WATER SUPPLY FOR THE LOCK CANAL AT PANAMA.



Mr. Sorzano.

*III.*—The Camacho Reservoir, in the same locality, in August, 1908, "had leaks that made it necessary to draw the water 18 ft. in order that the fissures in the trap rock of the side hills may be filled with clay to stop the leaks, it having been ascertained that the leaks are through the side hills."

*IV.*—There is nothing in the Canal Zone to show that the conditions of the trap rock in other parts of that vast lake bed, and under the standing forests, are not, and cannot be the same as those developed after one year of service in the Camacho Reservoir.

The conditions being the same, the results may be the same; and as Gatun Lake will be 2 780 times larger than the Camacho Reservoir, ar l also deeper, the risk of more fissures and crevices is correspondingly greater.

That the foregoing conditions deserved consideration is shown by a letter from Colonel Hodges, in which, referring to the rocks under the Gatun locks, he says:*

"The indications are that, under the lake head, there might be actual flow of water in the stratum of soft sandstone. This flow, of course, would be slow and general in its character, rather than localized in streams. Nevertheless it was thought best to stop it by the curtain wall, lest an actual material removal of particles of the sandstone might take place. * * * Furthermore, the test-pits indicated an underground flow from the eastward * * *."

No better evidence of a strong probability of percolation could be demanded than those words, from such an authority.

And, if such percolation is a fact in the small area where the locks happened to be located, why should it be impossible in the rest, or in any other part of that 240 sq. miles of lake bed?

The writer sees there a risk, and claims that no proper allowance has been made for it by the authorities now in charge.

The Comité Technique, for a lake of smaller size and only 60 ft. deep, assumed a percolation of 0.24 in. per day.

The writer, for a reservoir three times larger and 85 ft. deep—that is, for a risk more than four times larger—suggested a loss varying from 0.475 to 0.377 in.

Colonel Hodges evades the question by not mentioning any figure at all; and yet enormous curtain walls are being built around the locks, and borings and investigations are still going on at great cost. Why these expenditures, if there is no risk or even probability of loss of water by percolation? If there is the most remote risk, why not provide against it in the calculations?

In reply to the writer's assumption, Colonel Hodges only says: "The engineers on the Isthmus" are of the opinion "that the percola-

* *Engineering News*, December 2d, 1909, p. 617.

Mr. Sorzano.

tion through the bed and walls of the reservoir will not be a matter of serious importance."

The difference between an opinion and an engineering solution, is that one can be argued forever, the other—right or wrong—must assume a definite form, a dimension. If the figures in the tables are too high, why not change them, and see in what way the draft question will be affected?

As for the Camacho Reservoir, the figures given by Colonel Hodges, to use his own language, "require a little correction," for, instead of the "2 000 000 gal. daily" mentioned by him, the official report* gives the following statement:

"The average daily consumption from this reservoir was 1 210 988 gallons. At the lowest elevation reached during the year there remained in the reservoir sufficient water for but one day's use. * * *. This low elevation, and the consequent short supply in the reservoir, was due to the small rainfall on the watershed and to evaporation, it having been noted that even after a comparatively heavy rainfall a large percentage of the water was absorbed by the earth or evaporated by the intense heat of the sun, * * *."

A flagrant case of plain "fly-off," with perhaps a little unmeasured percolation through the bottom!

If the calculations of Colonel Hodges be corrected by the above official figures, his available amount of water in Lake Gatun would be only 2 522 cu. ft. per sec., instead of the 4 000 cu. ft. per sec. which he gives.

The writer, however, did not point to the Camacho Reservoir as a "horrible example" of water supply, but only as a simple local warning about percolation.

*Seepage and Percolation.*—Before preparing this paper, the writer analyzed very carefully the seepage experiments described by Mr. Hazen, and published in full in the Report of the Isthmian Canal Commission. Those experiments were made in small tanks (about 39 in. in diameter), to ascertain seepage conditions in various soils, in order to obtain data for the construction of an earth dam at Gatun.

In these experiments, the material was placed in the tanks by hand, and, as the report says:

"As far as possible, an effort was made to deposit the material in the tanks in a condition similar to that when found in place."

Under such conditions, it is obvious that cracks, fissures, seams, and crevices cannot be, and could not have been, "transplanted" and replaced in the small tanks in the exact condition in which they are found in Nature, and not even in a similar condition in regard to compactness, permeability, and dimensions of fissures, interstices, etc.

Under such circumstances, the data obtained by those experiments

*Report, Isthmian Canal Commission, 1909, p. 86.

were very useful in finding out how materials placed by Man will behave in a carefully constructed earth dam; but they will not show how water will behave in the cracks, seams, flaws, and fissures which have not been experimented on, but may have been on the ground just alongside of the materials tested. Mr. Sorzano.

If studying the construction of a reservoir, with its bed artificially formed by Man, with selected material carefully deposited, as far as possible in the condition in which it was placed in those experimental tanks, there is no doubt that the figures and data obtained and given out by Mr. Hazen, would have great practical value; and in that case no man could, better than Mr. Hazen, calculate to a nicety the speed at which seepage might affect that reservoir.

But, unfortunately, in dealing with an immense lake, with water 85 ft. deep, resting on natural, undisturbed ground, covering unknown substrata conditions, there is an element of risk which has not been measured in the tanks.

The seepage problems studied by Mr. Hazen are such as concern dams, canal embankments, filter beds, and other work executed by Man to retain water or to filter it, but they are not applicable to the question of percolation as presented in this paper.

As there is evidently a misunderstanding in the use of terms, perhaps a definition would not be amiss here.

By "seepage," the writer means that portion of rainfall or of any other water supply which soaks and sinks into the ground, by passing slowly through the mass of the soil, and reappears later at lower elevations.

Seepage is what produces simple moisture below embankments, springs, pools, and swamps, and feeds the streams during dry seasons.

As it is based generally on well-established and uniform conditions, which can be easily measured, its intensity can be calculated with good approximation, as in the experiments mentioned.

By "percolation" the writer means that amount of water which, after having passed through the top strata of alluvial soil, reaches the underlying rock formation and passes out through the seams, fissures, faults, cracks, or whatever other natural orifices may exist in the rock, and be sufficient to permit the water to pass slowly, and continue on its way to its ultimate destination—into the lower depths of the earth or into the ocean.

Percolation takes place, not through the mass of the rocks, but through the seams, flaws, and cracks; not necessarily by the shortest way, but by the easiest way, following the best downward passages.

Seepage and percolation do not exclude each other. They may go together; but, by the nature of things, seepage precedes percolation.

Mr. Sorzano.

Seepage flow depends on the local conditions in the upper strata: the composition of the soil, its permeability and topography; the density of vegetation, evaporation cracks, decayed roots, temperature of water, hydraulic gradients, meteorological influences, etc. These conditions being generally well established and combined in large, uniform masses, their results can be easily studied by samples representing such masses. Seepage velocity can be thus measured with sufficient accuracy.

Percolation, on the other hand, depends on conditions not generally as accessible to the investigator. It depends, not only on many of the above elements, but on the amount of water remaining after seepage; on the nature and composition of the rock formation; and on the presence of seams, cracks, faults, fissures, crevices, or other flaws which will permit the slow passage of water having head enough to force its way through such passages.

As these interstices and many of the other percolation elements are unseen and unknown, percolation speed cannot be calculated accurately in advance. It can be estimated approximately—by comparing cases, or by empiric rules combined with experience and judgment; but it cannot be measured to the fourth decimal place, as Mr. Hazen does when he names 0.0008 in. per day as the total loss on Lake Gatun.

There cannot be percolation if there is no water; but percolation is possible if there is water, particularly under the high pressure due to a head of 85 ft.

Perhaps a better classification or definition of these phenomena would be:

*Seepage.*—The oozing of water through the whole mass of saturated soil,

*Percolation.*—The passage of water through the small fissures in the rock formation,

*Leakage.*—An exaggerated percolation through larger fissures.

*Risk of Percolation.*—If the foregoing tentative definitions or distinctions are admitted, it will be seen that data obtained by the methods and experiments described by Mr. Hazen are not applicable to the question of percolation as raised by the writer. For it is obvious that there must be in the immense Gatun Basin thousands of places presenting spots 39 in. in diameter where there will be no flaws, as in the tanks, while just alongside of such favored spots, important fissures may be found for free percolation.

As three-fourths of the vast area of Lake Gatun is still unexplored, in fact, actually covered with top soil and dense vegetation, it is not known whether fissures or any kind of passages exist in that vast territory; hence the element of risk mentioned by the writer.

Mr. Sorzano.

That such risk exists, is proved by the large sums now being spent on the Isthmus in making studies, investigations, borings, etc., in order to ascertain the presence of flaws in the underlying rock of that basin.

If Mr. Hazen is so sure that the total amount of percolation in that basin, measuring more than 200 sq. miles, cannot even reach the unmeasurable amount, 0.0008 in. per day; if the authorities can be so sure in advance that the rocks, even if fissured, will permit the percolation of less than the solid specimens quoted in Table 9, why spend such enormous sums in building around the locks huge curtain walls—as those now being built—to prevent the passage of ground-water (percolation) through the rock under those locks?

If the reservoir at Gatun were a natural lake with a régime well established by years of service and sedimentation, the writer would not have raised the question of percolation risk; but it will be an entirely new reservoir, in which undiscovered elements may exist; and, under its 85-ft. head, new ones may develop. In both cases they should be provided for on the safe side, until their importance is ascertained.

In the Ashokan and Croton Reservoirs mentioned by Mr. Hazen, as in many others very favorably located, the question of percolation losses is not paramount, the locations having been selected just because the supply is known to be more than needed. Such municipal reservoirs have generally an ample and continuous supply. As long as it is sufficient for the estimated demand, perhaps with water running over the spillway, the losses by percolation or even by evaporation have no disturbing importance; but that does not prove that such phenomena do not take place in them.

These New York reservoirs were located where they are on account of the favorable conditions they offered; but the location of Lake Gatun was selected, not because it had the best soil on which to build a reservoir, nor an absolutely impervious one, but because it was the only spot where a large volume of water could be stored, and give an 85-ft. head.

Because there is no anxiety about evaporation and percolation in the Croton and Ashokan Reservoirs, would Mr. Hazen deduce from that, that Lake Gatun cannot or will not lose water by percolation and evaporation?

Experience all over the world proves that, if there are exceptional cases in which no appreciable loss is felt from percolation, there are also many other cases on record in reservoirs, mines, galleries, etc., where loss of water by percolation through rocks has been measurable, important, and sometimes ruinous; and this at places where least expected.

The Camacho Reservoir, built by American engineers, without

Mr. Sorzano.

restrictions of any kind as to cost and conditions, on a well-selected site, and on exactly the same kind of soil as that on which Lake Gatun will rest, in the same region and the same locality, has the following unfortunate record:

*"Leaks in the Camacho Reservoir.*

"Leaks in Camacho Reservoir near Empire have made it necessary to draw the water from elevation 358 to 340 [18 ft.] in order that the fissures in the trap rock of the side hills may be filled with clay. It has been ascertained that the leaks are through the side hills and that the dam is no way affected."*

Had a paper on the water supply of the Camacho Reservoir been written four years ago, mentioning the possibility of a loss of water by percolation in that reservoir, then being built, it would have been criticized in the same way as the writer is now being criticized in reference to percolation in Lake Gatun; but it would have been right. The risks were the same. Will the leakage be the same?

*Rate of Percolation.*—The writer has no particular interest in any special rate of percolation in Lake Gatun, in the intermediate canal, in Lake Miraflores, or in the Culebra Cut. After having stated in the paper that, while investigations in the Gatun Basin were going on, the question was somewhat a matter of guess, he, in order to complete his tables, had to enter in them some approximate, but definite, figure, on which to calculate the loss of depth in the lake. In consequence, he adopted a daily depression averaging 0.420 in., computed by an approximate empiric rule he has found very handy for quick preliminary work. He did not pretend that those figures were the only ones possible; he only hoped that any engineer analyzing the problem would substitute in the tables whatever figure he might consider nearer the probabilities of the case.

*Methods of Computation.*—There are evidently two ways to approach this much-disputed question: One—the writer's—is to estimate the risk, allow for it an ample provision, and feel safe; the other—Mr. Hazen's—is to disregard completely the element of risk, and, if anything happens, then to be "at a loss to account for this percolation through the material a short distance below the natural surface," as he says now in connection with the leaks in the Camacho Reservoir.

The explanations given on this matter by such an authority as Mr. Hazen are, it would seem, the best vindication of the writer's contentions that could be presented, and in consequence they are reproduced here, in full:

In speaking of the Camacho Reservoir leaks, Mr. Hazen says:

"The writer [Mr. Hazen] is at a loss to account for this percolation through the material a short distance below the natural surface. His first thought was that it might be due to the spaces left by decayed

**Canal Record*, August, 1908, Vol. I, p. 402.

roots, but observation in cuts showed that as a rule roots did not extend far into the soil, and the seepage was through a layer deeper than that to which roots ordinarily extend. The writer has been told that in very dry seasons there are shrinkage cracks, due to the continued extraction of moisture by roots, and otherwise by evaporation, from the clayey soil containing a large percentage of pores filled by moisture, and that these shrinkage cracks sometimes extend to considerable depths. It may be that these cracks when once formed do not completely heal in the ensuing rainy season, and that there may be seepage through them." Mr. Sorzano.

If, according to Mr. Hazen, because conditions in Gatun and Camacho are the same, there is no reason to apprehend more loss of water by percolation from Lake Gatun than from Camacho Reservoir, there is, according to the writer, no reason either to state that the loss by percolation will be less at Gatun than at Camacho.

If the rate of percolation at Gatun Lake should be no more—and no less—than at Camacho Lake, Mr. Hazen's 0.0008 in. will be utterly insufficient, and the figures suggested by the writer will be amply safe.

If the estimated water budget of the Lock Canal cannot permit a safety margin of 0.42 in. per day (only 1.23%) on a reservoir 85 ft. deep, then indeed the supply is insufficient, as it does not allow any leeway for contingencies, indispensable in all engineering undertakings.

### Silting in Lake Gatun.

The writer wishes to thank Mr. Paschke for the words of appreciation with which he so kindly accompanied his criticisms. He evidently remembers how welcome a refreshing shower is in the "dry season of a dry year."

The point raised by Mr. Paschke is well taken, and is perhaps one of the best arguments against the probability of an excessive percolation, say of 2 in. or more per day; but the question of silt, being so important, was carefully considered by the writer, and amply allowed for in the figures entered in Tables 4 and 6.

The empiric rule given by the writer for "probable percolation," in cases where substrata conditions are not known, is based on the precise assumption that the underlying rock is already covered with a top stratum at least equal to about the depth of water in the reservoir under consideration, at the different points of the basin.

According to that assumption, if the underlying rock formation should have seams, fissures, crevices, or any other outlets distributed in the basin, that empiric rule will give, with reasonable approximation —and on the safe side—the rate at which the level of the water will lower, making the thickness of alluvial soil a factor on equal terms with the head of water. This rule recognizes the influence of the thickness of soil and silt, as they are apt to be found in usual average conditions, that is, thinner where the water is shallow and thicker where the basin is deeper.

Mr. Sorzano.

There is no doubt that every freshet will bring a certain amount of new silt to the bottom of Lake Gatun. The writer studied this point very carefully, but believes that the quantity will not be as large as it might seem at first thought, for the following reasons:

*I.—The Higher Level of the Lake.*—By raising Lake Gatun 85 ft., the discharge plane of all the streams now emptying at sea level will be raised the same amount. The long distances that these streams now have to run, or rather cut, through the low alluvial soil to reach their destination, will be shortened, not by a few feet, but by scores of miles. The level of Lake Gatun will reach above Gamboa, as far as Alhajuela on the Chagres River, and, in the other parts of the Basin, for miles out of the Canal Zone, up in the hills, covering thus the lower and thicker alluvial soils, where they are to-day the more subject to attack and where the accrued currents are now more violent and effective. The erosion that takes place now in all the streams and slopes, in the 200 and more square miles of that basin below reference +85, will cease completely, and this, where it was the most active. Lake Gatun, by running up toward the hills, will drown and cover all the creeks, gullies, embankments, etc., in that territory, searching, so to speak, through the forests for all low points, and obliterating the cuts and silt-producing embankments, along them. As the slopes will be protected by the forests and undergrowth, the other places remaining where strong erosion will be possible are the bare spots and smaller streams on the higher hills; but there the rock is known to be harder, the alluvial soil thinner, the rainfall lighter, and the run-off less voluminous—conditions which will combine to reduce erosion.

*II.—The Porosity of the New Silt.*—Lake Gatun's bed will have perhaps 100 sq. miles of more or less submerged lake forests, in different conditions of growth. There will be from these forests a constant supply of dead leaves and other detritus which will be carried by freshets and intermixed with whatever silt may come from the hills above. This semi-vegetal silt, when water-soaked, will deposit in the lake, in a black, putrid mass, light and porous, in which measuring sticks will sink beyond reach. Such forest silt or mud is not impervious, and will not affect direct percolation. In that mud, the air entrained by the dead leaves will help fermentation during the dry season; this will add much to the offensiveness of the lake and increase the temperature of its water, thus indirectly facilitating again more loss by percolation.

*Inefficiency of Natural Silting.*—Experience in Holland and Italy has proved that natural silting—*colmatage*—does not create impervious strata. It has also proven in canals and reservoirs that very often natural sedimentation, even when helped artificially with the best clays, is not always reliable.

When it is deposited after heavy, sudden tropical freshets, it gen-

erally carries so much of other organic materials that its accumulation under the conditions probable at Gatun will not affect very much the permeability of the reservoir, and, it seems to the writer, not enough to prevent percolation under the high head that will rule on that basin. Mr. Sorzano.

If, instead of raising the lake 85 ft., it were lowered 50 ft., and removed 85 miles toward the ocean and—left there, the conditions would be different.

*Origin and Quantity of Silt.*—The solid matters removed from a drainage basin by freshets and run-off can be classified under three headings, namely: soluble matter, insoluble matter, and coarse sediment.

*A.*—The soluble matter of all kinds, dissolved by the water during its passage through the ground by seepage, or dissolved during the rains. This "washing" of the soil is the most important cause of denudation, as it is the one that carries away—slowly, but persistently—the largest amount of solid matter from any normal drainage basin. Its intensity depends on a multitude of conditions: chemical, geological, topographical, meteorological, physical, etc.; on the state of cultivation, the proportion of forests, of bare soils, etc., etc. The amount of solid matter taken from the soil by solution and carried away to the ocean by rivers or by percolation, may vary from 20 to 200 tons per sq. mile per year under usual average conditions. In some localities it may reach 300 and 400 tons per sq. mile per year. None of this matter produces any silting.

*B.*—The insoluble and very fine sediment carried by freshets, and remaining in suspension for some hours in the run-off water. This is the fine material that gives color to flood waters, and is carried for miles into the ocean, for example, by the Mississippi, the Amazon, the Orinoco, and the Ganges.

Contrary to general belief, the amount of solid matter removed during the year by this process is considerably less than by solution. In some cases it is less than 1%, up to about 10%, of total material removed.

This very fine, suspended matter would be, when deposited, the most effective against seepage, being generally composed of the finest and most plastic clays; but, on account of its tenuity, and the long time it takes to settle, much of that which enters Lake Gatun will be carried over the spillways during freshets, and only a very small fraction of an inch will be deposited every year. It has been calculated that, in the Great Lakes, it will take 200 000 years to deposit 1 in. of fine silt on the bottom.

If the catchment basin of Lake Gatun were not almost completely covered with vegetation, and thus well protected against surface erosion, it would take, under the worst conditions, about 96 years to deposit 1 in. of this fine silt over its whole bed.

Mr. Sorzano.

In Lake Gatun, this fine sediment will be mixed with the litter of dead leaves and other organic matter, which will make the deposit light and porous. If the density of natural soil (weighing 165 lb. per cu. ft.) is taken as 1, fine silt, as deposited in lakes, rarely reaches a density of 0.40 or 0.50. In tropical countries the lake muds, on account of the organic matters they contain, very often show less than 0.20 density. A foot or two of such light silt will not have much influence on percolation and seepage.

*C.*—The coarse sediment carried only by surface run-off during heavy rains and freshets. On the Gatun Basin, where all the ground—when not rock—is covered with dense vegetation, either grass or forest, and consequently well protected, the only important erosion possible is at the embankments, and beds of the streams. It is known, however, that on the hills, where the alluvial strata are thinner, the beds more rocky, the streams narrower, and the volume of freshets less—particularly in the streams which have been shortened by raising the lake level—the total amount of erosion will be less.

In suspended matter of a given density, the weight being proportional to "the cube" and the resistance to motion to "the square," sediment of large dimensions will settle more quickly than fine sediment. For this reason, the coarser silt will deposit at the entrance of the streams into the lake, and the less coarse material will be carried for a short distance and settle in the channels, forming the usual bars. These may have a thickness of 5 or 10 ft., or even more, in spots, and islets, but not all over, and as the very fine material has been washed out from this coarse sediment, what remains will be pervious and not to be relied on to prevent normal seepage, and will not affect percolation to a measurable extent, if at all.

### Lock Dimensions.

The lock calculations were based on the dimensions shown on the blue prints submitted to the Committee of the Chamber of Commerce, in March, 1909.

In those plans the locks were shown as divided, by intermediate gates, into two sections of 600 and 400 ft., to which must be added the extra length for safety appliances, and, on the upper locks, a rolling, safety gate, the wall recess of which will add about 45 ft. to the length of the water prism.

After the accident in the Sault Ste. Marie lock, on June 9th, 1909, this rolling, safety gate was abandoned, and guard chains were substituted. It seems, also, that, since then, the lifts at Miraflores and at Gatun have been decreased, in order to permit the utilization of the intermediate gates.

These changes will affect somewhat, and diminish, the volume of water per lockful; not enough, however, to modify to any extent the main question, the draft in the lake.

Mr. Sorzano.

The writer observes, also, with amazement that the lock sections will be now, according to Colonel Hodges, 350 and 550 ft., instead of 400 to 600 ft. They will be then 100 ft. shorter. To pass the 1 000-ft. vessels, specified by Congress, the inner gates must be kept open, leaving only one gate between the ship and the lake, thus eliminating one of the double safety appliances, which were so much heralded when the accidents happened in 1909, in the Sault Ste. Marie and in the Poe locks.

This shortening of the locks also reduces considerably the clearance between the ends of the ships and the gates, during lockage.

*Displacement of Vessels.*—There is not a single word in the paper to warrant Colonel Hodges in insinuating that the writer—in presenting the explanatory formula to emphasize the effect of the condition of the lock at the arrival of a ship—was not aware that the displacement of boats has no influence on water consumption. That blunder was perpetrated in a Lock Canal paper published in New York in May, 1909. Letters by the writer at that time and on that occasion, prove that the remark by Colonel Hodges was unnecessary, at least as far as the writer is concerned.

If intermediate gates are not used, it will take the same quantity of water to pass through the canal a 10-ft. naphtha launch as a 30 000-ton battleship. Perhaps a little less care would be needed for one and a few more strong words for the other, but the exasperating number of valves and gates to be operated is the same. This has been one of the arguments used so often by the writer during the past year, to show how the cost and exertions in the Lock Canal will not be proportionate to the results obtained.

*Intermediate Gates.*—It was after having read last year, in two pamphlets (by Colonel Hodges and General Abbot) the *"menu"* of the complicated maneuvers necessary in order to utilize the intermediate gates in the Gatun locks; it was after mature consideration of the human equation in connection with a "day-and-night-and-forever" operation of the locks, that the writer decided to assume in his calculations, that, after some time, the intermediate gates will not be used in the Lock Canal, even if they are ever used in the beginning.

Colonel Hodges' system of utilizing the intermediate gates at Gatun is remarkable, inasmuch as it alters the basic conditions under which the locks are to be operated—the continuous use of the locks by vessels following each other in each chamber—and leaves out the most important part of the proposition—the draft in the locks when saving water.

Colonel Hodges transforms the 3-flight locks at Gatun into a system of 2-flight locks, separated from a single-flight lock by a short canal, formed by the two inside sections used as an intermediate basin. To do this, the locks cannot be used in uninterrupted succession—one

Mr. Sorzano.

vessel following the other in each lock chamber. To do it, an empty section must be kept either ahead or behind each passing vessel, and all the craft must be of the same convenient small size. If they are not, he may lose with one large vessel what he gained on the others; if they arrive in mixed sizes, the complication of orders, signals, maneuvers, thinking, and what not, will be beyond what can be inflicted on a human being in that enervating climate.

In his very clever, but quite misleading algebraic demonstration, Colonel Hodges does not say:

*I.*—In how much he will reduce the available draft in the locks when dividing the contents of one full section into the other two empty ones.

This is important, if it be remembered that the commercial, small ships will have at least 25 or 26 ft. draft, and that a battleship that will fit in the smallest lock section may draw from 27 to 30 ft. in the fresh water of the locks.

*II.*—In how much he will reduce the capacity of the Canal by the boats not following each other in each section, when using the intermediate gates; and by his hazardous assumption that 80% of the vessels arriving at the Canal in the future will be small enough to use the intermediate gates.

*III.*—He does not give, even with reasonable approximation, the saving, if vessels of different sizes should demand passage in irregular order, and what would happen if they modify their order while passing each other in the lake.

*IV.*—Colonel Hodges does not say what the vessels in the twin locks will be doing, while he is borrowing water from one side to save water in the other, and to what extent this will add to the complicated maneuvers; and, after all this is done, how much will be the saving if the other lock also borrows water.

*V.*—Colonel Hodges does not give a thought to the number of regulations, orders, instructions, signals, and maneuvers, and to the fastening and unfastening, tightening and unwarping of mooring lines, cables, guard chains, opening and closing of gates, valves, etc., etc., that will be indispensable to carry out his elaborate water-economizing plans.

For it must be remembered that while this is going on in the locks, the other vessels on the approaches—in order to resist the swift currents produced by the emptying of the locks—must be also warped in place by several mooring lines on each side; they must be advanced step by step at each lockful, fastened and unfastened, stopped and started, and this all over again, as they approach the goal. They must advance at slow speed; they must each time come to a dead stop and to the mark, close to the gates. Any misunderstanding of orders means an accident. All that, by capstans, electric motors, and by signaling at great dis-

tances, to several boats down between huge walls; all that by day and night, rain or shine, every 2 minutes, forever. All that to save 15 or 20% of water! Mr. Sorzano.

The admission alone, by Colonel Hodges, that our naval and commercial ships will have to submit to such intricate maneuvers, to save that small quantity of water, is the most irrefutable proof that there is great scarcity of water; that the original amount is insufficient to maintain the draft necessary for convenient and unrestricted navigation.

If American engineers, in an American canal, do not simplify that system and use full locks, crowding in them the vessels as they appear, it will be indeed because there is not enough water with which to do it.

*Locks at St. Mary's Falls.*—The conditions in the locks cited by Colonel Hodges are not similar to those which will rule at Panama.

On the Great Lakes, all the vessels are getting to be of the same size, with a common well-known draft of not more than 20 ft.—limited by the Lakes. There are three single locks of different lengths; the vessels classify themselves, selecting the lock according to their dimensions—or, where the quickest chance of admission is seen. They move freely by their own power; any delay in one only gives an opportunity to the others to get ahead.

In Panama the vessels will have to follow each other in single file, and will be moved by outside mechanisms. Any interruption or delay in one will be carried all over the line.

At the Falls, the lift does not exceed 20 ft., no intermediate gates are used, no double gates, no extra safety appliances, no capstan traction, no long-distance signaling. The installation is the simplest imaginable, as it ought to be, in order to reduce the inconveniences of a lock to a minimum.

In those locks, no economy of water is needed, the supply being almost unlimited. The maneuvers are the simplest, the captains, being "regular commuters," are familiar with the conditions; they enter the lock as soon as possible and move ahead to get out as soon as they can. Even the construction of those semi-barges, loaded with ore and other cheap cargoes, facilitates such service.

On the Isthmus, on the contrary, the ships will be of all dimensions, conditions, and nationalities; many of the navigators will be unfamiliar with the surroundings, with the regulations, and with the language. The canal pilots, also, will not be familiar with the dimensions and steering qualities of the craft. Battleships of short length, extra draft, and great weight will demand extra care. The bumps that a lake barge loaded with lumber would receive as a matter of course, may cause serious damage to a *Dreadnought*.

The time and care for lockage will be increased in proportion to those difficulties. Any additional complications, only to save water, should be avoided.

Mr. Sorzano.

Colonel Hodges, in speaking of the Lakes, says: "Methods of carriage on the Upper Lakes have changed since then, the large single vessel having come to the front." Colonel Hodges, in a few years, when writing about his admirable work on the Isthmus, may have to say:

"The large single vessel prophesied by Sorzano is coming to the front."

## Hydro-Electric Plants.

When the Lock Canal is in operation, much power will be used on the Isthmus, not only to operate the locks and light the waterway, but to supply electricity to that region. More than 50 000 h.p. will soon be needed for the fortifications, the Panama Railroad, the industrial plants, the old cities, the new ones, for the pumping stations, the machine shops, cold-storage plants, coal yards, and for the thousand and one uses for which electricity has no equal. With the Sea Level Canal, all this electrical energy would have been obtained, at a profit, from the Gamboa Dam, and, at the same time, controlling the Chagres River. Additional hydro-electric plants could also be installed, if needed, on the various other cascades in the Zone, and in thus utilizing, at a profit, great natural resources while regulating those streams, the surplus water could be freely used for irrigation, and for other agricultural and industrial purposes, and thus contribute to the inevitable development and great productiveness in that region.

With the Lock Canal, according to Colonel Hodges, none of the water gathered in that 1 320-sq. mile basin can be used except for lockage, and all the power to be consumed on the Isthmus must be obtained by steam, with either coal or oil as fuel.

It was when comparing the difference in cost of operation of the two systems that the writer charged to the Lock Canal the cost of producing the needed electrical energy by steam and credited the sea-level waterway with the profits of its "white coal."

This was objected to by the Lock Canal advocates on the ground that 6 000 or 7 000 h.p. hydro-electric plants would be installed on the lake at Gatun, to produce that energy.

The writer, without believing that such a thing would be done, or even half of it, had to admit those figures—at least to prove their fallacy. Hence the two amounts entered in halves under the hydro-electric clause. It will be noticed that it is the only item that has been considered in halves. The writer was so sure that the supply of water would not permit such installations that he anticipated that alternative. He is gratified now to see that the hydro-electric plants will be of 2 000 h.p., and this only during the rainy season.

He can now place the original figures of comparative cost where they belong. He is, though, amazed at the facility with which Colonel

Hodges, in discussing these matters, can shift from water power to steam power, without giving a thought to the annual cost, in a country where coal costs $6.36 a ton, and oil $1.20 a barrel. The difference amounts to millions. Mr. Sorzano.

Cost of Saving Water.

*I.—By the Destruction of Water Power.*—Every horse-power obtained from a dam and delivered anywhere on the Isthmus in the shape of electrical energy, corresponds to an actual saving of $1 \times 4 \times 24 \times 365$, or 17.52 tons of coal per year.

In the Canal Zone coal costs $6.36 per ton.* Neglecting all the economies in general and local expenses, and the advantages of electricity, etc., and figuring on coal only, the saving on one hydro-electric horse-power will be per year:

| | |
|---|---|
| Coal only: 17.52 tons at $6.36 | $111.43 |
| Deduct, for any possible cost of distribution, above similar expenses in steam plants (the contrary being probable) | 11.43 |
| Net saving per horse-power per year | $100.00 |

Without penetrating too far into the possibilities of the future, and assuming the utilization of only 20 000 h.p. (for the Panama Railroad, the coaling stations, forts, pumping stations, lighting the cities and Canal, the harbors, the small towns, and their small industries), the net annual saving on coal only will be $2 000 000.

At the 2% rate of the Panama Canal bonds, this perpetual annual saving corresponds to a saving in value of $100 000 000, to be charged against the Lock Canal for destruction of water power only.

*II.—By the Destruction of Lands.*—Whatever may be the purpose for which land is considered, the possibility of using water adds much to its value. Any restriction or prohibition as to utilizing the streams makes the land valueless, particularly in the torrid zone.

In many parts of the United States sage brush without water is not worth $0.50 per acre; with water rights it will sell at $25. In Southern California good land without water can be purchased at $5 per acre; land of the same quality, similarly situated, but with water rights, is worth $150 per acre; and if under citrus fruit production its value may exceed $1 000.

In the tropics, lands near lines of communication have comparatively high prices, on account of the great profits possible if put under cultivation. Very few tropical cultures will yield less than $50 net per acre per year. Coffee, cacao, alligator pears, pineapples, vanilla, citrus fruits, rubber, and any truck gardening will net more than $75 per acre under usual conditions, and considerably more in favorable cases.

*Report, Isthmian Canal Commission, 1908, p. 40.

Mr. Sorzano.

In Cuba, Porto Rico, Hawaii, etc., lands near railroads sell at from $33 to $100 per acre, and sometimes rent for those figures per year.

On the Isthmus, land will offer conditions not to be found anywhere else in the tropics, as to peace, political security, sanitary conditions, immediate proximity to a railroad and to large cities, on an international canal where vessels coming from all distances will be the permanent market for fresh vegetables, tropical fruits, dairy products, etc.

With such favorable elements, it is to be expected that even the poorest lands of the Canal Zone will acquire a high value, comparable only to what is obtained in Cuba, near Havana. Under the circumstances, an average of $50 per acre would be low for agricultural lands, and considerably more could be obtained for building lots near the railroad and waterway.

"The United States Government has paid in the Canal Zone as much as $1 345, gold, per acre for lots near the Canal, by appraisal made by American appraisers, men of high character selected by the Secretary of War."*

And "the rates charged for rental of building lots in town vary from $202.34 to $1 214.04, gold, per acre per year."†

The remnant of the catchment basin, after filling Lake Gatun, will have 704 000 acres. A net area of 600 000 acres at $30 will represent $18 000 000.

If, instead of selling the land, it is rented at only $10 an acre, the annual income on 600 000 acres would be $6 000 000, which, at 2½%, is equivalent to a capital of $240 000 000 in gold.

This does not include the income from town lots, nor the other benefits from taxation, development of the country, commerce, etc.

It does not include the losses on the lands destroyed by Lake Gatun.

If, according to Colonel Hodges, these 704 000 acres cannot be permitted to use 200 cu. ft. per sec. of water for all their agricultural and industrial needs; if it "will be a very simple matter for the Government to stop any draft of water should it be found desirable," as he says, these 704 000 acres of land will be uninhabitable and useless; they will be no more valuable than so much sage brush, and not worth $1 an acre.

The losses due to the non-utilization of water-power and of land may be thus summarized:

| | Income. | Capital. |
|---|---|---|
| I.—To save hydro-electric water consumption, coal only, net | $2 000 000 | $100 000 000 |
| II.—To save "miscellaneous" consumption on catchment basin, agricultural only, if sold, $18 000 000; if rented. | 6 000 000 | 240 000 000 |
| Totals | $8 000 000 | $340 000 000 |

*Report, Isthmian Canal Commission, 1908, p. 847.
†Hearings, January 6th, 1909, p. 80.

Mr. Sorzano.

These are only round figures. An itemized account, including building lots, and land losses under Gatun Lake, shows much heavier loss.

The above amounts are sufficient, here, to give an idea of what this nation will sacrifice to save a few inches of depth in Lake Gatun, during the dry season only.

If, to save 240 cu. ft. per sec., this nation has to lose $340 000 000, each cubic foot per second will cost $1 400 000.

There must be scarcity of water, indeed, when we are compelled to pay $1 400 00 per cubic foot per second; $340 000 000 to save 0.06 in. per day on the lake.

### Losses at Gates and Valves.

Colonel Hodges says:

"If it be assumed that there is an opening $\frac{1}{32}$ in. wide around the meeting faces of the effective gates and valves, the leakage at Gatun will not reach half the amount mentioned by Mr. Sorzano."

The writer agrees with that, but does not believe that the enormous lock doors can be operated within a $\frac{1}{32}$-in. fit all around.

In the Lock Canal the openings will be 110 by 80 ft.—more than half of a city block in width, and the full height of a 7-story building. Each leaf will be 65 ft. wide, up to 80 ft. tall, of steel-sheeting construction; each leaf will weigh 640 tons, and will hang on two strong trunnions.

These huge leaves must rest against each other on the center line at an angle, and abut against the quoins on each wall. For each gate the total length of joint is 370 ft. To prevent extra leakage, heavy greenheart timbers are usually bolted on the seats, to seal the joints. As it is impossible, in practice, to make these leaves rest evenly on the whole 370 ft. of joints, they are generally built, as it is called, "long," so that, after having been worn down by service, and at the trunnions, they still remain long enough to rest against each other on the center line and resist the pressure of the water.

These "long" leaves do not touch the miter sill, on its whole length in the bottom; in closing the gate, one leaf rests against the sill, and the other on the vertical edge of the first one, at a distance of 1 or 1½ in. from the sill. This forms at the foot of the gate a triangular passage 1 or 1½ in. at one end, 0 in. at the other, and 65 ft. long, measuring more than 2.7859 ft. clear area for the passage of water at the bottom of the lock. It is easy to calculate the quantity of water that will pass through that opening under a head of 30 ft., or at any other average depth.

As the trunnions and seats wear out, the leaves may reach a better fit, but only to pass it as soon as attained. At no time can these huge doors be made to rest evenly all around the 370 ft. of contact, or

Mr. Sorzano.

at $\frac{1}{32}$ in. from it, because they are not machine-faced, unyielding doors, bolted down in place, but elastic, movable, rectangular steel boxes, made of riveted sheeting, subject to a diversity of ever-varying strains; and they will be at all times subject to variations of temperature. In a climate where the thermal difference between sunshine and shade is from 30 to 40°, expansion and contraction on a double-sheathed door 65 by 80 ft., with half of its length under water and the other half in the sun, will prevent the maintenance of any uniform fit, if it could be attained. Moreover, grit, detritus, dead leaves, floating litter, irregularity of construction, dents, rust, variations in the wear of the trunnions, pivots, and seats, haste in closing gates, particularly at night, etc., all these elements will combine in practice to prevent ideal conditions.

Under the circumstances, it is wise to make allowance for emergencies, and estimate on a little more than $\frac{1}{32}$-in. play.

For smaller gates and smaller locks the Board of Consulting Engineers figured at the rate of 278 cu. ft. per sec. for the Gatun locks. The writer, to avoid controversy, used the same figure, adding only 17 cu. ft. per sec. to compensate for the larger valves, the higher lift at Miraflores, and the higher temperature of the water.

Colonel Hodges has not made any allowance for these increased items, but has used for the larger valves, the figures originally calculated for the small ones.

In connection with these large valves, it is well to remember that some of them will be at all times under a 60-ft. head. Against such pressure, they have to be operated quickly, every few minutes—by machinery acting on many valves at a time. To be perfectly tight, all, and every one, must close to a mathematical fit; any irregularity in the wear of the seats, of the gear or of the spindles, etc., will modify that theoretically perfect contact; and as they do not empty in the open, where any leakage could be observed, one or more valves imperfectly closed while passing a vessel, may be losing tons of water without showing signs of it, the outlets for such leakage being for each lock chamber 65 openings, 3 ft. 10$\frac{7}{8}$ in. in diameter, covered by more than 13 ft. of water always in violent agitation.

As there is nothing to prevent a leaking valve from operating, it is more than probable that, in the long run—particularly at night—the monotony of the work will breed neglect, and much water may be continually escaping without affecting the service, and without being noticed.

Under the circumstances, the 12 cu. ft. per sec. allowed by the writer would seem conservative to a practical engineer desirous of providing against inevitable "little things."

*Losses by Maintenance.*—If the quantity of water that can be lost at gates and valves is a "matter of guesswork," to provide against it is a matter of good engineering judgment.

Mr. Sorzano.

If Colonel Hodges has a sure way to operate a system costing more than $80 000 000, having more than 100 000 tons of metal work, the greater part of it under water, with innumerable valves, pipes and chains, miles of culverts, driving gears, and what not, all under the most trying conditions of perpetual operation, in the tropics, and has the assurance that such a system will have no accidents and will need no repairs, except during the rainy season, or at his convenience, he has indeed a "pull," that no other man ever had in those regions.

It is just because light repairs can be carried over to the wet season that the writer believes they will cause such a loss of water. If a damaged valve could be repaired at once, the water wasted would not be worth considering; if, on account of necessities of the service, a disabled valve is kept in that condition for weeks, until the beginning of the wet season, it will be leaking all that time. If any of the numerous leather packings forming the seats of those immense valves in the locks, should be damaged, worn out or need replacement, and, if this were not done until the end of the season, the loss of water would be serious.

In the tropics true "wrought iron," if well cared for, does good service; but steelwork—particularly in or near water—has no lasting qualities. To those who are not prepared for it, it will be a revelation to see how rapidly the steel plates on the inside of the air chambers in the gates will rust, particularly if, in the lake forests, there is a certain kind of tree which abounds in that neighborhood.

*Water Lost by Accident.*—To the thousand and one accidents mentioned by the writer must be added the one that happened in the Poe Lock after the paper was printed. The writer had only said, in reference to such accidents, "they may happen." They did happen.

Colonel Hodges can easily ascertain how much water was lost in the Sault Ste. Marie accident by calculating the quantity which would flow in 36 hours through an opening 80 ft. wide and 20 ft. deep under a permanent head of 20 ft. That will be more accurate than information gathered from other sources.

*Safety Appliances and Towing Devices.*—When discussing (in April, 1909) questions in regard to the safety devices adopted for the locks, the writer ventured to say that the "rolling gate" shown in the plans would not be used, and could not be relied on if installed; that it would not be called in service for small vessels, and, when needed for large ones, it would be found to be out of order, or with its tracks—in the wall recess—clogged with silt, dead leaves, and gravel. The reply to this was: "I guess we can afford to trust in the engineers we have there." The year is not yet over, and that rolling safety-gate, which was going to prevent all kinds of accidents, has been abandoned.

Now, the writer ventures to say that the adopted safety system of capstans, cable-drives, etc., to move all vessels in and out of the locks, is dangerous, and will also be found to increase considerably the compli-

Mr. Sorzano.

cations and risks of lock operations, particularly when working "single-track," Colonel Hodges' opinion notwithstanding. For one reason or the other, that complicated and annoying system of maneuvering craft will be, sooner or later, "side-tracked." Colonel Hodges says that the working of a double-track traffic momentarily as a single-track operation will "introduce * * * no element of danger not present in the double-track operation." It does not introduce new danger, but it increases it. Any superintendent of traffic, any train starter, any signal man, will admit that.

To do the double service on one lock, the capstans and cable-drives, proposed by Colonel Hodges to pull the vessels going one way, will have to "push" those going the other way.

*Water Economy.*—The writer cannot agree with Colonel Hodges' ideas of 100% efficiency in the operation of locks within their strict lockage volume, nor with his absolute saving of water during the operation, maintenance, repair, and renewals in the lock system, at all times.

In a canal which will be in constant service day and night—and forever—under all aggravating conditions of speed, monotony of work, trying climate, etc., it will not be possible to maintain a high standard of water economy not obtained or even approached anywhere else. Great economy of water in locks is very much like saving food when paring potatoes: Any professor can prove how thin the skin is and how easy it is to peel it economically; but where is the cook who will do it?

As soon as the canal begins to prove its success, the tendency will be, not to save water, but to break records.

*Miscellaneous Losses.*—Colonel Hodges, in discarding absolutely all the miscellaneous losses mentioned by the writer, leaves out one of the most important elements in the water-supply problem. Against his undemonstrated opinion, the writer offers the following figures:

*I.*—Lake Gatun will receive all the run-off from the 1 320 sq. miles of the catchment basin. No additional drainage basin is available for it in the whole Isthmus.

*II.*—After filling Lake Gatun, there will remain a territory of 1 200 sq. miles, or 768 000 acres, the greater part of it extending outside of the Canal Zone.

By creating that lake, the Lock Canal engineers will obliterate from the map more than 180 000 acres of land, which is extremely valuable on account of its proximity to the inter-oceanic route, and its position on the Panama Railroad between two large international shipping ports. Such land, in other parts of the tropics, would be worth from $33 to $100 an acre, and could be rented for agricultural, industrial, and dwelling purposes at from $10 to $100 per acre. The loss in capital, rental, and taxable value of these 180 000 acres is a direct, irremediable loss occasioned by Lake Gatun.

The United States is a great nation, and can afford such a waste; it is also powerful, and can do what it pleases on the Isthmus; but will

it be to its interest to annihilate also the future value of the 739 000 acres of land remaining in that catchment basin just to save 0.05 in. of water per day on that lake? Mr. Sorzano.

Will it be to our interest (if it were right) to prevent the development of that 1 200 sq. miles, just to save only 6 in. of draft in the lake during the dry season?

Under our flag, assured of peace and good government, in close proximity to two main arteries of communications between two continents and between two oceans, that land would soon acquire a value comparable only to that of the best districts in Cuba. On all the hills and valleys of that vast tract of land, tropical plantations, small farms, ranches, villages, establishments of all kinds, would soon develop under our protection. For the people, their farms, their cattle and their mills, water is needed, and water could be taken anywhere, freely, under the Sea-Level Canal plan.

Under the Lock Canal plan no such use can be made of the water without draining the lake. According to Colonel Hodges: "It will be a very simple matter for the Government to stop any draft of water should it be found desirable. It is not part of the duty of the Canal to supply them."

And all that to save 6 in. of draft during the whole dry season!

After such admissions it is almost unnecessary to continue to prove insufficiency of water. The writer, however, has to show how he arrived at the 300 cu. ft. per sec. he entered in the tables, which will give that 0.05 in. of depression on the lake per day.

The figures are as follows:

| | Cubic feet per second. |
|---|---|
| For 250 000 acres in plantations, farms, truck gardening, orchards, etc., partly irrigated during the dry season, from the streams | 125 |
| For 350 000 acres in grazing pastures, ranches, dairies, etc., and the live stock | 118 |
| For 139 000 acres of land and the settlements on them; villages, summer resorts, mills, hospitals, schools, barracks, fortifications, canning factories, abattoirs, gardens, lawns, sprinkling of streets, live stock, etc | 50 |
| For the Panama Railroad, used between terminals, for locomotives, stations, about | 1 |
| For craft on the lake: The water of Lake Gatun will be so loaded with organic matter and so uninviting during the dry season that it will not be necessary to forbid its general use by passing vessels; but some will be used by the power-houses, factories, etc., and by condensers | 1 |
| For use by the inhabitants of the 116 islands in the lake, the fishermen, and in the inland harbor, about | 1 |
| For the losses at the intermediate section and at Miraflores Lake. Using Colonel Hodges' evaporation data, the 2½ sq. miles of water surface will lose | 14.90 |

Mr. Sorzano.

| | Cubic feet per second. |
|---|---|
| Border elevation and fly-off | 0.50 |
| Percolation, seepage through embankments, to avoid controversy, no charge | 0.00 |
| Total losses for the 1 320 sq. miles | 311.40 |

Less inflow to Lake Miraflores:

The streams that will empty into that lake yield practically no run-off during the dry season, the amount being insufficient for the towns now. The writer believes that Balboa will develop into a large, prosperous port, consuming more water than Panama uses now, and that an additional supply will be necessary.

The independent sources of water supply for Lake Miraflores do not amount to 0.70 cu. ft. per sec. during the dry season. It was gauged below the lake, opposite Kilometer 55.50 for three years, 1890-91-92, and gave the following dry-weather discharge for four months:

| | |
|---|---|
| January | 1.48 cu. ft. per sec. |
| February | 0.56 " " " " |
| March | 0.39 " " " " |
| April | 0.35 " " " " |
| Averaging only 0.695 cu. ft. per sec., say | 1.40 |
| Total net miscellaneous losses | 310.00 |

The writer, to facilitate calculations, used only 300 cu. ft. per sec.

If, to save that small quantity of water every year, we have to prevent forever the material development of those 1 200 sq. miles of territory; if we have to prevent the truck gardener from watering his plants, the cattle from drinking, our soldiers from bathing, the schools and hospitals from washing their floors; then, indeed, the water supply is insufficient, and will have cost us too much.

*Sea-Level Water Supply.*—The statement made by Colonel Hodges that, with the Sea-Level Canal, the vessels to get water would have to do as with the Lock Canal, is, to say the least, astonishing. In all the discussions about the Sea-Level Canal, the great argument, up to the present time, has been the superabundance of water in all directions, particularly in the canal prism.

With a Sea-Level Canal, the Gamboa Reservoir and all the other streams would have furnished freely and in abundance, not only for the vessels, but for irrigation and for all other demands, all the year around, on the whole territory. As for the Sea-Level Canal itself, being fed at both ends by the oceans, its supply would be forever unlimited and free.

*Capacity of the Canal.*—In résumé, it may be said that the figures given by Colonel Hodges are based on unsupported and undemonstrated assumptions or opinions, which do not cover the margin of safety, and have not the accuracy, that a question of this importance demands.

Mr. Sorzano.

Colonel Hodges figures on a replenishing supply of 1 190 cu. ft. per sec. for a dry year, when records show that in a year like 1908, the quantity would not be 900 cu. ft. per sec. as things are now, nor even 700 cu. ft. per sec. after the lake is filled.

He assumes only 85 cu. ft. per sec. "for seepage, waste, etc.," in a lump, when any one of these items may exceed that total; when General Abbot, the Lock Canal authority on its hydraulics, figures on 154 cu. ft. per sec. for one of the items only, the seepage.

He assumes only 930 cu. ft. per sec. for evaporation, without allowing any amount for wind, temperature, increased area of lake, or evaporation on the forests and borders, when the most conservative calculations, corrected for the Lake Gatun conditions, give a loss of 1 668 cu. ft. per sec.

Colonel Hodges allows nothing for normal wastes in the operation of the locks, nor for repairs, accidents, usual irregularities of service, false maneuvers, etc. He figures throughout on 100% efficiency. He allows nothing for miscellaneous losses on a whole territory measuring 1 320 sq. miles, nothing for the agricultural, industrial, and living necessities. In figuring lockage consumption, he uses the theoretical product of length by width by depth, and, to make the amount thus obtained sufficient, he assumes an arbitrary classification of the vessels of the future, relying on a certain percentage of small craft conveniently sized to meet the scarcity of water—with "some squeezing" if necessary.

Fortunately, Colonel Hodges very kindly gives these assumptions, as he says, for what they are worth. The writer, in consequence, will leave it to the reader to compute their value and accuracy from the standpoint of the immense interests at stake.

In reply to Mr. Saville, the writer again calls attention to the fact that in preparing this paper, he made an effort to use only figures published in the official reports of the Isthmian Canal Commission, or adopted, or given out by its engineers, in the official documents, particularly in the report of the Commission for 1908—the last issued at the time the paper was written.

Mr. Saville has had an experience of only a few months in tropical countries. The writer was born and raised in the tropics; his life work has been there, in a branch of engineering depending to a great extent on meteorology, geology, and hydrography. After 40 years of such engineering and business experience in these countries, it has been quite interesting to him to read Mr. Saville's statement: "that knowledge gained solely from experience there [in the United States] would almost inevitably lead astray in the interpretation of Isthmian records."

The writer cheerfully concurs in that statement.

Mr. Sorzano.

*Conditions of Meteorology.*—The meteorological conditions which Mr. Saville describes so clearly, and which seem to him so remarkable, or peculiar to the Isthmus, are those which generally prevail in tropical and semi-tropical countries: Cuba, Porto Rico, and other islands in the West Indies, Hawaii, etc., etc. In those islands the difference in rainfall between the leeward and the windward sides, as in the Canal Zone, is so marked that plantations only a few miles apart have to be operated under totally different systems. On one side of the hills the rainfall is abundant and amply sufficient for all the needs of the crops; on the other slopes, immense sums have to be spent to secure and store the water necessary for crops of the same kind.

Table 1, to which Mr. Saville seems to object, is absolutely correct and complete for the year 1907-08. It was compiled carefully from the weekly and monthly reports published by the Engineers of the Panama Canal in connection with their shovel work. In such cases the tendency would naturally be to give maximum rainfalls, but the writer had no doubt that the figures were accurate. They have now proved to be absolutely accurate.

Table 22, copied from the Report of the Isthmian Canal Commission for 1909, just published, gives the rainfall for 1907-08.

TABLE 22.—INCHES OF RAINFALL PER MONTH, IN THE CULEBRA AND CHAGRES DIVISIONS, FOR THE FISCAL YEAR, 1907-1908.

| Month. | Bas Obispo (or Chagres). | | Empire. | | Culebra. | |
|---|---|---|---|---|---|---|
| | Wet. | Dry. | Wet. | Dry. | Wet. | Dry. |
| July, 1907 | 8.25 | ..... | 9.89 | ..... | 9.31 | ..... |
| August, 1907 | 12.69 | ..... | 11.24 | ..... | 11.81 | ..... |
| September, 1907 | 14.71 | ..... | 10.86 | ..... | 11.38 | ..... |
| October, 1907 | 13.62 | ..... | 15.44 | ..... | 15.27 | ..... |
| November, 1907 | 9.85 | ..... | 10.40 | ..... | 6.91 | ..... |
| December, 1907 | ..... | 2.26 | ..... | 1.47 | ..... | 2.30 |
| January, 1908 | ..... | 0.20 | ..... | 0.75 | ..... | 0.91 |
| February, 1908 | ..... | 0.11 | ..... | 0.00 | ..... | 0.01 |
| March, 1908 | ..... | 0.41 | ..... | 0.41 | ..... | 0.13 |
| April, 1908 | ..... | 1.81 | ..... | 1.36 | ..... | 1.67 |
| May, 1908 | 13.18 | ..... | 12.91 | ..... | 12.43 | ..... |
| June, 1908 | 6.55 | ..... | 8.21 | ..... | 8.86 | ..... |
| Total amounts | 78.85 | 4.79 | 78.95 | 3.99 | 75.97 | 5.02 |
| Writer's figures, in Table 1 | ..... | 4.79 | ..... | 3.99 | ..... | 5.02 |

The figures in Table 22 are exactly the same as those given for the dry months in Table 1, and they show how marked the 5 lean months of the dry season are, when compared with the other 7 wet months of plenty. Table 1, however, was not prepared for the purpose of determining the available water supply, but only to show at a glance the difference between the dry and wet seasons, in a "dry year"; and also their relative lengths. In that table the writer included also the

Mr. Sorzano.

Rio Grande station, to show the dryness of that section, as this is a very important element when considering the water budget of Lake Miraflores, and of the streams that will run into it.

Any loss of water in that lake by evaporation, percolation, fly-off, etc., will have to be made up by Lake Gatun, if, as is the case, there are no other sources of supply in that drainage basin, during the dry season.

There was certainly more good reason to give the rainfall at Rio Grande* than that of the Cristobal station, given by Mr. Saville in Table 14. This Cristobal station is outside of the catchment basin for Lake Gatun, and located where rainfall conditions—as Mr. Saville admits—are very different from those prevailing in the central region, and in the hills from which Lake Gatun will be supplied, particularly in the Alhajuela region.

Had the writer entered the Alhajuela figures in Table 1, he might have been accused of favoring his own views too much, for Alhajuela station, which covers the greatest area (427 sq. miles) of drainage basin, represents the interior section where, as Mr. Saville says: "the rainfall is very much less * * * than at other places in the Chagres Basin."

Table 11 shows that out of a total 1 320 sq. miles of basin, the interior sections are:

| | | |
|---|---|---|
| No. 1, above Alhajuela | 427 | sq. miles |
| No. 2, between Bohio and Alhajuela | 352 | " " |
| Nos. 3 and 4, above Lagartera | 314 | " " |
| Representing | 1 093 | sq. miles |

of "less rainfall section," on a total of 1 320 sq. miles.

*Average Run-off and Yearly Averages.*—The serious objection to Mr. Saville's criticisms is that he quotes and gives tables of "average rainfalls," "average of years," etc.; for example: 39 years average at Cristobal (which is outside of Gatun Lake Basin, in the heaviest rain section on the sea-shore, and far from the region of normal conditions); 26 years average at Gamboa, 15 years at Bohio, etc.

In studying problems of scarcity of water during "the dry seasons of dry years," the figures showing the "grand average of 39 consecutive years" are not relevant; they cannot have any weight; they are misleading, inaccurate, and dangerous. It will not help the scant water supply of the lake in a year like 1908, when the total inflow was only 800 cu. ft. per sec., to remember that 2 years before it was 2 600 cu. ft. per sec., or that the annual average of 36 years is 5 788 cu. ft. per sec.

* Plate 83 of the Report of the Isthmian Canal Commission for 1909 shows that Rio Grande Reservoir is inside of the crest line for Gatun Lake. Fig. 4 in Mr. Saville's discussion shows also the Rio Grande Reservoir inside of the outline of the Chagres River Drainage Basin. They are both wrong. The 1 320 sq. miles of drainage basin given by Mr. Saville include the Rio Grande Reservoir Basin. Previous reports of the Isthmian Canal Commission gave the total basin as 1 200 sq. miles. The writer computed on 1 320 sq. miles.

Mr. Sorzano.

What is needed in the "dry season" of a "dry year" is water, and not the figures of times of plenty, as given by past records.

If the question of depletion of a reservoir is being considered seriously, it would seem that the calculations must be based, not on averages, but on the well-established records of a minimum year. Any other method would be as dangerous as calculating the capacity of a spillway on figures of average years, instead of on maximum data.

For these reasons, the writer regrets to have to say that the tables given by Mr. Saville have not the value that could be expected from such a high authority.

*Location of Gatun Lake.*—Mr. Saville says: "It must be remembered that nearly three-quarters of the total lake area is in the region exposed to the heavy precipitation of Gatun and Bohio."

The run-off does not depend on the lake area, but on the area of the drainage basin. This, according to Mr. Saville, is 1 320 sq. miles. Lake Gatun is 165 sq. miles, three-quarters of it, say 124 sq. miles, being in the region of heavy precipitation. This leaves 1 196 sq. miles of catchment basin to be reached by the clouds after they are greatly depleted—as Mr. Saville says—and for that reason, 1 196 sq. miles of diminished rainfall area, an important fact to remember when considering the reduced run-off caused by filling the lake.

Mr. Saville, in quoting the writer from page 66, "during the 3 to 5 months of 'dry weather,' the rains * * * in dry years," left out the most important part of that sentence, its last three words: "in dry years."

He not only truncated that sentence, but, immediately after, gives Table 13, showing, not the figures of "dry seasons in dry years," but averages of 4 years, 15 years, etc., and the averages for years of record, selecting those of maximum rainfall, giving in full the year 1908-09, in which the dry-season precipitation was the highest on record for 40 years.

In Table 13, are shown the following dry-season rainfalls, applicable to the larger part of Gatun Lake:

| | | | |
|---|---|---|---|
| At Gatun, | 1908-09.....18.31 in., | 4 dry months | |
| At Trinidad | " .....21.89 " | " | |
| At Gatun River | " .....25.66 " | " | |
| At Bohio | " .....21.92 " | " | |

This is an average of 21.94 in. for the 4 dry months, equivalent to a dry-season run-off (according to that table) of 23 258 cu. ft. per sec.

How will calculations based on 23 258 cu. ft. per sec. stand in a lean year like 1903, when the total run-off was only 1 191 cu. ft. per sec. (for the same 4 months); or the year 1907-08, when the total discharge (4 months) was less than 900 cu. ft. per sec.?

Mr. Sorzano.

It is indeed unfortunate that, in criticising the writer's general descriptive statement about "the dry months of dry years," Mr. Saville (probably under extreme pressure of active business) had to use figures of the largest rainfalls on record, or even averages including such "rainiest" years.

The writer fully sympathizes with Mr. Saville and the engineers on the Isthmus about "the d——d wet seasons," but cannot agree with him in considering "wet weather" a season when the rainfall averages very often less than 2 in. per month, and sometimes less than 0.68 in. per month, as it did in 1908, less than 0.002 in. per day, or 0.014 in. per week—not enough to make up in one week for one-tenth of one day's minimum evaporation.

Neither can the writer agree with Mr. Saville as to the length of periods between dry years, which he gives as once in 20 years, for he says: "The 4 months' discharge, given for a minimum year such as may occur once in 20 years," though on the same page, a few lines above, he says: "Previous to 1908, the minimum run-off of the Chagres River was that of the dry season, 1903." The lapse of time between the "dry year, 1903," and the "dry year, 1908," is 5 years, and not 20 years, as Mr. Saville inadvertently states.

An analysis of the rainfall on the Isthmus for years back will show that the ever-recurring "dry years"—like the extra wet years—come at periods approximating 5 years apart rather than 10 or 20 years.

*Minimum Year Discharge.*—Mr. Saville gives—without specifying the year—the minimum run-off available for Lake Gatun during the dry months, as follows:

| | | |
|---|---|---|
| 3 months | ..... | 930 cu. ft. per sec. |
| 4 " | ..... | 1 191 " " " " |

On a lake having an area of 160 sq. miles (average of Lake Gatun at average height), these discharges would give in 24 hours, an accretion, or increase of depth as follows:

| | | | |
|---|---|---|---|
| 3 months at | 930 cu. ft. per sec. | = | 0.2533 in. per day |
| 4 " | " 1 191 " " " " | = | 0.3245 " " " |

which is almost exactly what the writer calculated, and entered in Tables 4 and 6, as follows:

| | From Table 4. | From Table 6. |
|---|---|---|
| 1st month ..... | 0.3466 in. | 0.3466 in. |
| 2d " ..... | 0.2118 " | 0.2127 " |
| 3d " ..... | 0.2790 " | 0.2884 " |
| 4th " ..... | 0.4810 " | 0.4895 " |
| Average for 4 months, dry season.. | 0.3296 in. | 0.3343 in. |

These figures prove that the writer credited the lake with a daily accretion even larger than called for by Mr. Saville's figures. They

Mr. Sorzano, show also, incidentally, the extreme accuracy and care with which the writer's figures were computed, as they agree almost to the third decimal place—on the safe side—with data now published for the first time, one year after the paper was written.

This lengthy dissertation about minimum run-offs is to prove that the 1 200 cu. ft. per sec. adopted by the writer in his calculations for the "dry months of a dry year" is not only reasonable and conservative, but on the generous side of the argument. That amount is larger than the 1 000 cu. ft. per sec. very wisely assumed by General Abbot when studying these problems for the Canal Engineers.

The writer believes that, with time, when deforestation takes place in the Canal Zone, the difference in run-off between dry and wet seasons will be still more marked than at present; the discharge of the 7 months (May-November) will be heavier, with more freshets; and the run-off of the dry season (December-April) will be less.

In tropical countries, where there is no melting snow, if deforestation does not diminish the annual water supply, it alters considerably its distribution and regulation.

*Area of Lake Gatun.*—The areas and capacities given by Fig. 4 are interesting as approximate data. The two curves shown in that diagram cannot be accurate representations of the areas and capacities of the lake at various levels in such extremely variable ground as that destined to form Lake Gatun. Such ideal curves are possible only in an absolutely regular basin, such as a parabolic or spherical bowl would be, and if the 118 islands distributed so irregularly in the lake were all perfect prisms or pyramids.

These curves, accurate at Elevation +85, do not indicate the irregularities due to the remarkably varied slopes on the islands, hills, promontories, gullies, and ravines; nor do they show the appreciable area and volume occupied by the Panama Railroad's immense embankment through Gatun Lake, and by the considerable stumpage of more than 100 sq. miles of forests which will stand in the lake.

*Active Area of the Lake.*—When discussing surface evaporation, it is not the "paper area" of the lake, as measured by a planimeter, between contour lines, that is of interest, but the active evaporative surface of water in actual contact with the air—the surface where evaporation takes place—which is evidently considerably larger than the "paper surface."

It is on the "active surface" that the writer figures evaporation after having given due consideration to the many small items that tend to increase it.

An idea of the importance of these apparently insignificant elements is given by the following:

(*a.*) The stump of a dead tree, 4 in. in diameter, standing in the lake, will occupy a paper area of only 12.57 sq. in. Under 12 in. of

water oscillation and corresponding capillary motion, the same trunk will present to the air an active area equal to 204 sq. in., or a gain of 17 times the area occupied by the stump. Mr. Sorzano.

(*b.*) A pound of water, occupying 12 sq. in. when at rest, if churned by the propeller of a passing steamer, or by a strong wind, in a spray of $\frac{1}{16}$-in. globules, will present to the air an active surface of 20 sq. ft.; 240 times the original paper area on the calm water.

On Lake Gatun there will be at all times at least forty steamers in motion, churning tons of water. The writer will not attempt to estimate the effect of their propellers, circulating pumps, etc., nor the increased active surface of the lake due to waves, billows, white-caps, etc., it being so evident that all these elements disturbing the lake surface will increase considerably its "active evaporative surface," in contact with the atmosphere.

This is a point that has not been mentioned and, apparently, has not even been considered, by the engineers who have written on the Panama Canal. To obtain the evaporative loss, they simply multiply the flat "paper area" of the lake by evaporative units obtained in tanks, 10 in. in diameter, of perfectly calm water protected from the direct rays of the sun.

General Abbot, when figuring the loss of water by evaporation for the minority of the Board of Consulting Engineers, multiplied the area of Lake Gatun at Elevation +85, which he took as 111 sq. miles, by 0.24 in., with no allowances for temperature, wind, waves, increased areas, activating elements, lake forests, borders, nor any of the other influences.

Now, Mr. Saville proposes, or defends, the same crude method, but using even a smaller unit of standard evaporation, even less than the 0.233 in. actually measured on the Isthmus, in the year under discussion.

Table 17 shows that in the Canal Zone in the 4 months, January-April, 1908, the evaporation for the three stations was at the rate of 0.233 in. per day.

*Inaccuracy of Evaporation Methods.*—The Panama Canal engineers now gauge the evaporation by the "pan method," which Mr. Saville frankly admits is defective. In the case under discussion it is more than defective, it is inaccurate, because no records are taken of the simultaneous temperature of the water and of the air, the action of the sun's rays, the intensity of air currents, and the combination of these elements, nor the distance from the water level to the edge of the tanks.

Mr. Saville, describing the methods used now by him, says: "The records from Ancon and Cristobal are from insulated pans 10 in. in diameter and 3 ft. deep."

He forgot to mention the very important point that these pans are

Mr. Sorzano.

protected from the direct rays of the sun. Readings obtained in small pans, protected from the direct rays of the sun, unless properly corrected according to the thermal conditions, are valueless as standard units for a lake that will be exposed to the searching, almost vertical, rays of the sun in the tropics.

It is indeed remarkable that, after so many years of American occupation, and with such very able men in charge, the only data now available for calculating the probable evaporation on Lake Gatun should be based on approximate figures calculated years ago by General A. P. Davis, M. Am. Soc. C. E., for Lake Nicaragua, or on incomplete data obtained on the Isthmus under the following inaccurate conditions:

I.—At Ancon and Cristobal, both outside of the lake's basin, on the sea-shore, and in tanks protected from the rays of the sun.

II.—At Brazos Brook and Rio Grande, both outside of the lake's basin, in floating tanks, admitted by Mr. Saville to be an imperfect method.

III.—No corrections for temperature of water, distance of water level from edge of pans, no simultaneous records of rainfall, air currents, etc., at the same station.

IV.—Two flat tanks on the ground in the jungle, where any wild animal or any local precipitation may, in a few minutes, invalidate a whole week's record.

V.—The Bas Obispo station has been abandoned because it did not represent the normal conditions of the lake basin.

The foregoing conditions show that Mr. Saville is not in a position to advance any figures based on scientific, accurate data, obtained under scientific conditions in the Gatun Basin.

As for the method used by General Davis on Lake Nicaragua, it cannot be correct except under the following conditions:

*A.*—If the exact area of Lake Nicaragua is known,

*B.*—If the fluctuations of level in Lake Nicaragua are known,

*C.*—If there are no local precipitations on the lake or in any part of its immense basin while the measurements are being taken.

*A.*—The area of Lake Nicaragua is not accurately known, not even within a reasonable approximation, such as is necessary for a computation of evaporation. Its area has been obtained roughly by triangulation, but there are hundreds of miles of its contour still unsurveyed, unmeasured, unexplored; there are hundreds of islands, creeks, gullies, promontories, border-swamps, winding streams, etc., of unknown areas. Under such circumstances it is impossible to calculate accurately a loss of water based on the extension of the lake's surface. Any figures

obtained by dividing a daily loss of water by that unknown area will evidently be an unreliable unit for comparison. Mr. Sorzano.

To show how impossible it is to estimate, even approximately, very large areas like the Nicaragua Lakes when detailed contour lines are not at hand, one has only to consider the case of Lake Gatun at Elevation +85, as estimated by General Abbot for the Board of Consulting Engineers, in connection with the lock canal project.

In spite of the very complete and elaborate plans in the archives of the Panama Canal Company, in spite of the complete set of cross-section plans covering the whole Isthmus, every 20 meters apart from Colon to Panama, in spite of other accurate data at his disposal, General Abbot and the other eminent engineers of the lock canal, after having fully studied the subject on the ground, estimated (in 1906) the area of Lake Gatun, at Elevation +85, as 111 sq. miles. The exact area is now given as 165 sq. miles—an error of 50%, not as much as we are now used to on Panama Canal matters, but sufficient to vitiate any calculation based on the former figure.

*B.*—If the difference of level, due to currents, backing of waters by wind, local showers, etc., can be established accurately at the moment of measuring the small differences due to evaporation, or the variable inflows, etc., without knowing the exact mean level of such a large lake as Nicaragua, it is impossible to know its actual running contents at the moment of gauging the streams. A steady breeze in the lake will back the waters 3 or 4 ft. one way or the other, and modify accordingly, not only the apparent contents of the lake, but the flow of the streams under measurement at the time.

*C.*—In reference to local precipitations on the lake, or in any part of its immense basin while the measurements are being taken, there are hundreds of streams in the Nicaragua Sierras with unexplored drainage basins, covering thousands of square miles, and at great distances from the gauging stations. It would require thousands of rain gauges to keep simultaneous records of that region, extending nearly from one ocean to the other, in the most capricious climate of Central America.

It would require only one unrecorded shower in those remote basins to flood in a few hours any of those unknown streams, and render useless the most beautifully calculated evaporation data.

It is evident that General Davis did not control such favorable conditions, nor others so necessary for the accurate gauging of the inflows and outflows to and out of Lake Nicaragua. It would require years of comparative analysis between rainfall, lake references, and all the other elements, to arrive at even an approximate result which would permit one to quote, by this method, daily evaporation (by fractions of an inch) on a lake of that enormous size.

The writer does not believe General Davis ever intended that his ap-

Mr. Sorzano.

proximate Nicaragua figures should be used to decide between 0.2454 and 0.2400 in., on questions of scarcity of water in another region, under different local conditions.

For these reasons, the writer believes that the 0.19 in. calculated by Mr. Davis at Nicaragua is not a sufficiently accurate unit to be used as a base of discussion for the Canal Zone, particularly when the very records at the Isthmus actually show a daily evaporation (dry season 1908) of 0.2330 in.

In Tables 4 and 6 the writer figured on:

| | |
|---|---|
| Table 4, Average of 4 dry months in a dry year..... | 0.2712 in. |
| Less, actual precipation on lake, in a dry year.... | 0.0222 " |
| Actual calculated evaporation on lake..... | 0.2490 " |
| Table 6, Actual calculated daily evaporation on lake 0.2656 in. — 0.0237 in..... | 0.2419 " |
| Average..... | 0.2454 " |

Mr. Saville, in discussing the paper, did not notice that the writer —to avoid undue criticism—did not use in the tables the high evaporation figures which he believes will rule on Lake Gatun. He has been compelled to enter and follow Mr. Saville in these arguments on a small difference of only 0.0054 in., which is nothing compared with the extra evaporation from the forests.

In reply to the statement that the writer did not have more complete data, or that his figures appear to be "more excessive than anything that has thus far been observed at Lake Nicaragua, by either the 'pan' or 'lake' method, or on the Isthmus," the writer wishes to say that his reasons for believing in a high evaporation on Lake Gatun are based on:

I.—The high temperature of the semi-stagnant waters of Lake Gatun during the months of February-April,

II.—The action of the wind,

III.—The presence of large areas of forest standing in the lake,

IV.—The increased "actual evaporation" on the lake caused by the combined effect of all the elements enunciated in preceding paragraphs.

As these questions have not hitherto been mentioned by any of the investigators of Panama Canal hydraulics, the writer feels the necessity of explaining his views in more detail.

*I.—Result of Temperature of Water and Air.*—Fortier, the very able experimenter of the United States Geological Survey, says:

"Results show that an increase of 10° Fahr., will increase the evaporation from water surfaces 1 in. per week, or 0.1428 in. per day."

Mr. Sorzano.

In Table 18, the monthly mean temperature for January-April, is given by Mr. Saville as 97.40° Fahr., and the maximum for these months as 102.2° Fahr. The writer, however, finds in the *Canal Record* for 1908 (the year under discussion) the following maximum temperatures:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Maximum temperature in the sun at Empire, | | | | January, | 1908, | 125° | Fahr. |
| " | " | " | " | February, | " | 124° | " |
| " | " | " | " | March, | " | 125° | " |

Taking only the low figures given by Mr. Saville, however (which are probably of some wet year), and considering that the evaporation data on the Isthmus are taken in the shade at an average temperature of 78°, it will be seen what an immense increase in evaporation will result from the difference of temperature by Mr. Fortier's rule of 0.14 in. for each 10° Fahr. increase of temperature.

It is well to mention again the startling fact that the evaporation data in the Canal Zone are obtained "by means of tanks exposed to all atmospheric conditions except the direct rays of the sun."* This will perhaps explain why Mr. Saville and his associates do not believe in high evaporation.

The writer's figures are for a lake exposed to the direct action of the rays of the sun at the high temperatures on record there.

*Temperature of the Lake Water.*—It is regrettable—indeed inexplicable—that, in a discussion on the temperature of lake water "during the dry season of dry years," Mr. Saville should offer Table 21, which covers only the months from June to November—the rainy season, and of 1909, the rainiest year on record.† From that table are omitted the months of December, January, February, March, and April—the only ones that are of interest, and the only ones to be considered in a question of temperature of accumulated water in a reservoir during the dry season.

Instead of giving the figures for a season in which the total rainfall was:

| | | | |
|---|---|---|---|
| January, | 1908 | 0.75 | in. |
| February, | " | 0.00 | " |
| March, | " | 0.14 | " |
| April, | " | 2.00 | " |
| Total | | 2.89 | in. |

accumulated new rainfall, Mr. Saville gives the figures corresponding to the wet season of 1909, in which the same reservoir received 107.86 in. of new rainfall.

* Report, Isthmian Canal Commission, 1909, p. 21.

† The year 1909 was also the coldest on record on the Isthmus.

Mr. Sorzano.

The amount of fresh, cold water that the reservoir received in the period chosen was 39 times more than the amount received during the dry season under discussion; its cooling effect on the contents of that reservoir would be in the same proportion.

Even incomplete and irrelevant as Table 21 is, it shows that, even in that small reservoir, during the season in which it was receiving every day copious inflows of cool water, and with its top surface water running over the spillway, that water still acquired a temperature of 7° or 8° above the temperature of the ambient air.

In that reservoir, 220 ft. above sea level, in the midst of the full rainy season, the surface temperature reached 90.7° Fahr., 18° higher than the incoming water. At that rate, using the figures in Table 18, the surface of Lake Gatun would have a temperature of more than 106° Fahr. In order to avoid criticism, the writer named only 90°, which happens to be even less than the 90.7° registered in 1909 at the Rio Grande Reservoir, during the coolest months on record for 34 years.

As the temperature of Lake Gatun is one of the most important elements to be studied, the following considerations are necessary here: Lake Gatun will have a capacity of 185 000 000 000 cu. ft. After a few days of dry season, the inflow into the lake will average—in dry years—say 1 200 cu. ft. per sec. The greater part of that amount will follow the current toward Pedro Miguel to feed the locks there, and in consequence will not come to the lake proper. The other part, say 47 000 000 cu. ft. every 24 hours, at a temperature of about 75° Fahr., will run into the lake and mix with its bottom waters; but it will not remain in the very bottom—being somewhat less dense than the extra concentrated alkaline waters of the lake. It is this equilibrating effect of temperature *versus* alkalinity, impurities, etc., that confirms the writer in his opinion that the temperature in the stagnant waters of the lake will be about 82° Fahr. in the deeper bottoms, during the dry season.

Under the circumstances, it is easy, but tedious, to prove that with such a rate of 47 cu. ft. of fresh cool water against 185 000 cu. ft. of old warm water—with ordinary evaporation—the lake would very soon acquire a very high temperature, in a country where the hours of sunshine are more than 83% of the possible maximum.

If there were no more evaporation than the 0.19 in. suggested by Mr. Saville, the lake would soon have a surface temperature of 117° Fahr., and considerably more in the shallow parts and in the land-locked bays, where large areas of stagnant water are connected by narrow channels. Any argument to sustain the contention that the surface temperature will be low, will be a proof that evaporation has been high.

In connection with the foregoing, it is well to remember, also, two other causes of increased temperature:

Mr. Sorzano.

(*a*).—The fermentation of the immense amount of organic matter that will accumulate in the lake from the vast forests drowned in it, the detritus, dead leaves, and also the offal from all craft afloat in Lake Gatun.

(*b*).—The direct heating of the lake waters by the circulating water of the condensers of such craft, and of power plants, ice-plants, and many other industries which will be located on the shores of the lake, and will use its waters. It is easy to calculate that 50 or 60 vessels, constantly in the lake, each averaging only 2 500 h.p., 10 000 h.p. at Gatun, only 10 000 h.p. for the other industries, say 150 000 h.p., will heat 144 000 000 cu. ft. of water per day to 120° Fahr. or considerably more than 300 000 000 cu. ft. to 110°, and very much more as the mean temperature of the lake increases. For these reasons, the writer claims that the 90° he gave—so conservatively—will be surpassed.

That figure was not copied from "formulas connected with the movement of ground-water," but was based on the foregoing rough calculations, assisted by the writer's long experience in connection with the temperature of stored water in the Tropics.

*II.—The Action of the Wind.*—Air currents have a great effect in increasing evaporation. The result is almost exactly proportionate to the velocity of the wind. The gentlest breeze affects it; on a warm day a stiff wind will double the loss of water from a pool of stagnant warm water.

Fig. 6, prepared by Mr. Saville to show evaporation and allied phenomena, gives at a glance a very clear idea of the influence of air currents on evaporation. In that diagram the parallelism between the evaporation curve and the wind velocity curve shows how closely they follow each other, not only in their magnitudes, but in their angles, peaks, depressions, and irregularities. Nothing could show better how air currents affect evaporation. Fig. 6 also shows that for every mile of wind velocity there is an evaporation of 0.994+ in., almost exactly the empiric rule of 1 in. of water a month, for every mile of velocity of the wind per hour.

At that rate, a gentle breeze of 10 miles an hour—so common in that locality—will evaporate 0.33 in. per day.*

Fig. 6 also shows very clearly that evaporation is very low during the rainy season (May-November), and is at its maximum during the dry season (January-April), with the highest in February and March, as given by the writer in Tables 4 and 6, and on page 70, written a year ago.

* The Chief Engineer of the Panama Canal (Report, Isthmian Canal Commission, 1909), speaking of that region, says: "Limon Bay is exposed to northers and to heavy seas caused by the trade winds which prevail during the dry season."

Records on the Isthmus show wind velocities of 20 and 32 miles in that vicinity. It is the extra evaporation caused by the trade winds and permanent breezes that cools those regions and makes them habitable.

Mr. Sorzano.

Incidentally, the vapor pressure line (in Fig. 6) shows the insignificant and irregular effect that element has on evaporation.

The great difference, shown by this diagram, between the evaporation of the dry season and the loss during the wet season—almost double—proves how inaccurate it is to take the average of the whole year to calculate losses during the dry months only, or, even to use the dry-season average in computing the loss on a lake for any given month.

*III.—The Action of Forests Standing in the Lake.*—Probably the highest unit of natural evaporation is the one produced by tropical plants standing with their roots under water and their foliage out in the open hot atmosphere of a tropical region, particularly if there are air currents.

Assuming an average height of trees of only about 30 ft. on the slopes of the islands and hills, Lake Gatun will have, when full, more than 75 sq. miles of forests standing in its waters, under the foregoing ideal conditions for maximum fly-off, that is, water absorbed by the plants and evaporated from their foliage.

This fly-off is an extra loss, to be added to the actual evaporation on the lake's surface. Experience shows that the "accelerating" effect of this fly-off is considerably more than the retarding effect of the diminished air currents, shade, floating dead leaves, etc., produced by the same forests.

According to the combined data obtained by Fortier and Fernow, who have carried on such interesting experiments in this direction, this fly-off will produce, under the foregoing conditions, an evaporation of from 1 in. to 2.02 in. per day. Other experimenters have found even more.

Taking only 1 in. a day, and allowing for condensation, dew, periodical effect of the moon, the extreme density of the forests, fogs, etc., and, on the other hand, considering the very high temperature of the surface water, the hilly locality, and the varied height of the forests due to the irregular basin, it will be admitted that these "lake forests" will still produce an extra evaporation of considerable importance, and which, if distributed on the original "paper surface" of the lake, would enhance very materially the final, net coefficient of daily evaporation per unit of lake surface.

This fly-off, due to lake forests, is an element which has not been considered by any of the engineers of the Panama Canal.

Its importance will be felt there as it has been felt in other countries, where it has been found necessary to girdle the trees or cut down the lake forests in order to save water.

In Lake Gatun, after some time, many of the half-drowned trees will die; others will thrive luxuriantly. Girdling will be an expensive and inefficient remedy, as it will leave standing the dead trees as an

unsanitary, perpetual, and offensive source of decomposing organic matter during the dry seasons; or a serious danger to navigation, and to lock gates during freshets. Mr. Sorzano.

The only effective remedy will be to cut down and burn the trees. This, on only a small part of the lake basin (between Elevations +50 and +85), at $50 per acre, will cost more than $2 500 000.*

*IV.—The Combined Effect of the Foregoing Elements.*—The writer, after having given in the paper his reasons for a heavier evaporation on Lake Gatun than could be measured by gauging instruments alone, very plainly said:

"The actual daily loss of water by surface evaporation, if it could be measured accurately on the lake, would be found to be much larger than what has been assumed as an average for Lake Gatun, and nearer the following figures * * * for the five months of dry weather."

This means the actual loss of water that will take place, not in a tank 10 in. in diameter, with perfectly calm, cool water, protected from the direct rays of the sun, but on a lake having more than 170 sq. miles of surface, exposed to the active evaporative elements, so tediously described in preceding paragraphs.

Mr. Saville does not seem to have considered this problem of evaporation from this true, practical point of view. Under the circumstances, no agreement with the writer is possible, particularly if Mr. Saville continues to use the very crude "pans" which he himself admits to be imperfect.

*Border Evaporation.*—Mr. Saville, evidently, has not had time to consider border evaporation as it deserves, or he would not attempt to measure it by using flat pans 10 in. deep placed on the ground in the jungle, and by which he expects to obtain information.

Such pans, on the ground, surrounded by rank tropical growth, will show only such surface evaporation as the peculiar conditions permit—in the shade, in calm water, and reduced air currents—but not the border evaporation and fly-off which will be taking place from the moist soil around the pans, and due to the rank tropical plants which are smothering the pans. If no wild animals disturb them during the night, these jungle pans may perhaps show an evaporation of about 0.09 in., while the moist, saturated ground around them will be losing at the rate of 0.75 in. or more per day.

Mr. Saville has confused surface evaporation, on the water around the edges of the lake, with the border evaporation on the ground, or beach, above and beyond the edge of the water.

This border, referred to by the writer, is the ground around and above the contour line of the lake, kept moist by the fluctuations of

*The denser forests in the inaccessible regions of the lake basin cannot be cleared for double that price.

Mr. Sorzano.

the water, due to waves, etc., and by capillarity. According to the topographical and geological conditions of these beaches, the width of this border of moist soil may vary from 1 or 2 ft. to as many hundred feet and more, due to the extreme irregularity of the serrated contour of the lake, as may be seen on Plate VI.

*Percolation.*—The writer believes that many engineers who have had experience in storing water will agree with him that quite a loss of water is possible by percolation in deep reservoirs on unprepared ground. Perhaps many will recall reservoirs which have lost water even after having been cemented, or made water-tight by artificial means and at great expense.

Without leaving the Canal Zone, the experiences in the Brazos Brook Reservoir and the Camacho Reservoir, prove that, even in that region, in well-studied reservoirs built on natural ground, the water sometimes percolates through the bottom and sides to such an extent that they have to be emptied in order to be cemented, and their sides raised to make up for the losses by percolation.

In municipal reservoirs in the United States, like those Mr. Saville names, the replenishing supply is generally ample, continuous, and more or less variable, but safe; the consumption of water being also continuous, with water perhaps running over the spillways, it is not necessary to measure, or even to know, the exact amount of percolation. Under such circumstances, this becomes a more or less interesting side issue but without great importance as long as the replenishing supply is ample, or water runs over the weirs; that these reservoirs are operated under such conditions all over the world is not an absolute proof that there is no percolation from them.

The fact that the engineers for New York City's new supply do not feel any anxiety about Ashokan Reservoir does not prove that there will not be any normal loss of water there, nor is it a guaranty that there will be none under the completely different geological, topographical, and meteorological conditions in the Gatun Basin, particularly if the inevitable high temperature of the lake water is considered.

Tables 2 and 3 were given by the writer in order to emphasize possible conditions.

A fair-minded reader will admit that the writer never proposed to strip the whole 167 sq. miles of area, as Mr. Saville insinuates. The writer plainly said:

"Unless the whole 200 sq. miles of that valley be stripped and examined, this probable percolation cannot be estimated in advance, even approximately. Unless every square foot of that vast area is made impervious by artificial means, the loss of water by seepage cannot be authoritatively dismissed as 'an impossibility.' It can only be guessed at now, and will be ascertained only after the lake is filled."

Mr. Sorzano.

There is nothing in that quotation to show that the writer recommends, suggests, or in any way advocates the extravagance of stripping that lake basin.*

The purpose of that phrase was to present the element of guess overhanging a proposition in which three-quarters of that basin was still under the original condition of virgin forest. The testimony given by various engineers now in the Canal Zone, and on record, proves that they also admit this element of risk, mentioned by the writer. The great amount of exploration work, borings, etc., done at great expense since this paper was written, and still going on in the lake basin, under the direction of Mr. Saville, is the very best proof that the elements of risk suggested by the writer deserved consideration.

The question of percolation is somewhat like the item of fire insurance in a factory. When estimating his budget, a good manager would not leave out entirely the fire risks, because other factories do not burn down, or because his well-studied one is not expected to be destroyed by fire. No matter how well built and protected his mills are, he will be wise to figure on a premium to cover any possible risk. If he does not know in advance what the rate will be in that neighborhood, he will prove his sagacity by not figuring on a minimum.

At the time this paper was written (in April, 1909) many of the data now given out by Mr. Saville for the first time, were not even in his possession, as the explorations, borings, etc., to which he now refers had not been completed, and some of them not even started.

The more Mr. Saville and his able assistants investigate, explore, and study the geological conditions—hitherto covered under tropical forests—the more the percolation problem will shift from "scientific guess" to practical data, and the more that risk will diminish.

In this respect it is interesting to note that General Abbot, while with the Comité Technique, admitted a percolation of 0.24 in. a day; later, he reduced his figures to 77 cu. ft. per sec., and later he increased them to 89 cu. ft. per sec.

The method used by the writer to measure probable percolation was by a depression of a fraction of an inch on the lake's surface, the question under discussion being the depth of water in the lake. Any one disagreeing with him on that figure can use any other amount—this will only affect the depth of water in the lake according to that change and no more. The arrangement of the tables permits more than fifty-six alterations. The reader will keenly appreciate the fact that it is not necessary to argue on each one of them here.

There are a few other points in Mr. Saville's criticism which the writer must in turn criticize. In reference to the rock found in the ridges of the lake bed, he says:

* The author would call Mr. Saville's attention to the fact that the amount of land surface in the lake basin below Elevation +85 is not 167 sq. miles, but considerably more.

Mr. Sorzano.

"It was practically impervious to the flow of water. The seams and fissures in this rock are not abundant, nor do they appear to be of great extent, etc., etc."

It was Mr. Saville himself who said:*

"Some of the rocks [in the Gatun Valley] are of open texture and permit the flow of water" (p. 127).

"The principal water-bearing medium seems to be the joints and seams which cut through the various strata and allow the passage of large quantities of water" (p. 127).

"It [the material] has well-defined joint planes and seams through which water passes into the pit with velocity enough to throw the stream from 1 ft. to 1½ ft. into the opening" (p. 165).

He also says:

"That these streams continue to be fed and to run down the hillsides in periods of little rainfall is evidence of the water-tightness of the rock in the ridges."

This is also strong evidence of the permeability of the same overlying stratum on which Mr. Saville relies so much for protection against percolation.

If the top-soil were not quite impervious, if the rocks were not quite compact and were little fissured, the percolation figures would not be the small fraction of an inch assumed by the writer, but an enormous leakage which the writer has not claimed nor prognosticated. The ⅜ in. assumed as a coefficient of safety against an unknown and undecided risk in (at the time) an unexplored basin, does not seem to him so extravagant, for 85 ft. depth of water, if compared with the ¼ in. assumed by the Comité Technique for a lake only 60 ft. deep and much smaller in area; a difference of only ⅛ in. of water per day, on a risk four times larger, is not beyond engineering conservatism, considering the importance of the consequences if a mistake were made.

In regard to the amount of percolation admitted by the Engineers of the Lock Canal, no higher authority than Colonel Goethals, the Chief Engineer of the canal, could be named. When interrogated on the subject (January, 1909), he testified as follows:

"That question has been brought up, but the discussion is an academic one entirely. A surveying party is out now making a careful survey and investigation of all the saddles bordering the lake. We do know there is a pond back of the railroad at Gatun on the re-located line which maintains its level, there is no seepage. We do know the Brazos Brook Reservoir, with an area of 140 acres and depth of 34.5 ft., constructed in the hills near Mt. Hope, has no appreciable leakage through the hills. We have another at Camacho, 38.4 acres in area and

* Report, Isthmian Canal Commission, 1908.

55 ft. deep, and we have another at Rio Grande of 72.9 acres and a maximum depth of 57 ft., with the cut relatively near. There is no leakage through the hills. I do not see any more reason to expect seepage from Gatun Lake through the hills than from these reservoirs." Mr. Sorzano.

Inasmuch as the Camacho Reservoir had leaked, in August, 1908, so badly that it had to be emptied 18 ft. to be made impervious, the writer, using Colonel Goethals' own words, does not see any more reason to expect less percolation through the vast Gatun Basin than actually occurred in the Camacho Reservoir in August, 1908.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

# TRANSACTIONS

**Paper No. 1146**

## THE IMPROVED WATER AND SEWAGE WORKS OF COLUMBUS, OHIO.*

By John H. Gregory, M. Am. Soc. C. E.

With Discussion by Messrs. Joseph W. Ellms, Julian Griggs, C-E. A. Winslow, R. D. Scott and R. F. McDowell, Samuel Tobias Wagner, J. Corbett, W. R. Copeland, W. A. Sperry, J. W. Sale, C. P. Hoover, C. B. Hoover, A. Elliott Kimberly, Samuel Rideal, Alexander Potter, Gilbert Fowler, William Gavin Taylor, Allen Hazen, William B. Fuller, Emil Kuichling, Langdon Pearse, Rudolph Hering, George A. Johnson, George W. Fuller, and John H. Gregory.

In 1904 the City of Columbus, Ohio, began the construction of two important sanitary improvements which have recently been completed, and it is the purpose of this paper to describe them. They include works for improving the water supply and for purifying the dry-weather flow of sewage.

Previous to 1904, or, more correctly speaking, previous to the completion of the new works, it may be said that conditions in Columbus, as in some other American cities, were far from satisfactory. The water supply, which had been mainly from ground-water sources, but was augmented at times by drawing directly from the river intakes, normally very hard, had gradually grown worse, typhoid fever had been a constant menace, a very severe epidemic having occurred in January and February, 1904, and on more than one occasion a water famine had been imminent. In periods of extreme dry weather, practically the whole flow of the Scioto River above Columbus was taken for water supply purposes and returned to the river as sewage a

* Presented at the meeting of March 2d, 1910.

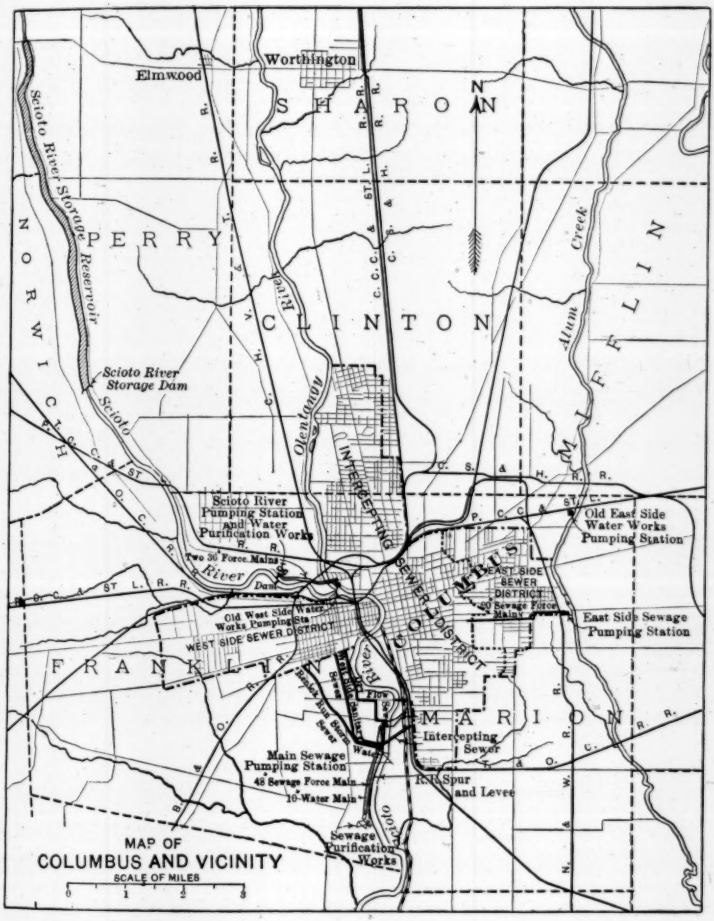

Worthington
Elmwood
SHARON
PERRY
CLINTON
NORWICH
FRANKLIN
MARION
Scioto River Storage Reservoir
Scioto River Storage Dam
Scioto River
Olentangy
Alum Creek
INTERCEPTING SEWER DISTRICT
COLUMBUS
Scioto River Pumping Station and Water Purification Works
Two 30" Force Mains
Old East Side Water Works Pumping Station
EAST SIDE SEWER DISTRICT
20" Sewage Force Mains
East Side Sewage Pumping Station
Old West Side Water Works Pumping Sta.
WEST SIDE SEWER DISTRICT
Intercepting Sewer
Main Sewage Pumping Station
48" Sewage Force Main
16" Water Main
R.R. Spur and Levee
Sewage Purification Works
MAP OF
COLUMBUS AND VICINITY
SCALE OF MILES
0 1 2 3

FIG. 1.

short distance west of the southerly part of the city, causing thereby a nearly stagnant pool of slightly diluted sewage, the odors arising from which, carried up into the city by the prevailing winds, gave cause for great complaint. A somewhat similar condition of affairs existed on the east side of the city, where the sewage was discharged into Alum Creek. Before proceeding to the detailed descriptions of the works built to relieve these conditions, certain general information relating to the city will be given.

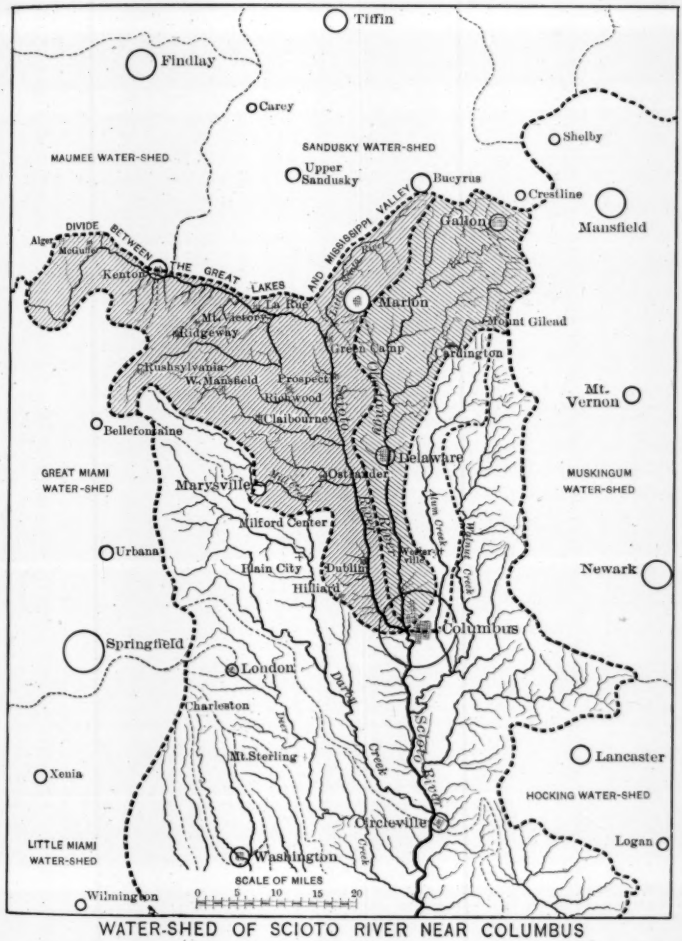
*Location.*—Columbus, the capital of the State of Ohio, is an inland city located about 30 miles southwest of the geographical center of the State, and about 100 miles from Lake Erie. The general elevation of the city is about 780 ft. above sea level. Fig. 1 is a map of the city and vicinity.

*Population and Area.*—The population of Columbus, as given by the United States Census, was 88 150 in 1890, and 125 560 in 1900. The growth of the city has been very rapid in recent years, and, from the best information obtainable, it is believed that the population in 1907 was about 170 000, and that, by 1910, it will have increased to about 200 000. The area within the corporate limits of the city in 1908 was 16.81 sq. miles.

*Precipitation.*—The mean annual precipitation at Columbus, from the records of the Weather Bureau of the United States Department of Agriculture, for the 29 years, 1879 to 1907, is 36.75 in. The wettest year was 1882, with a total precipitation of 51.30 in., and the driest, 1901, with a total of 26.53 in. The greatest monthly precipitation was 9.59 in., in May, 1882, and the least, 0.18 in., in November, 1904.

*Temperature.*—Tables 1 and 2 contain data relative to the temperature conditions in Columbus, also compiled from the records of the Weather Bureau. Table 2 is of especial interest as indicating the severity and duration of the periods of cold weather to which the sewage purification works may be exposed. The severest period in the past was probably in the winter of 1898-99, when, although the total number of consecutive days that the temperature was below 32° Fahr. was only 13, on 10 days the temperature was 20° or below, on 7 days 10° or below, on 4 days 0° or below, and on 2 days —10° or below.

*Water-shed of Scioto River.*—Columbus lies at the junction of the Olentangy and Scioto Rivers. Above the junction the water-shed of




WATER-SHED OF SCIOTO RIVER NEAR COLUMBUS

FIG. 2.

the Scioto has an area of about 1 050 sq. miles, and that of the Olentangy about 514 sq. miles; below the city, at the site of the sewage purification works, the water-shed of the Scioto, shown in Fig. 2, has an area of about 1 580 sq. miles. Above Columbus this water-shed is in general flat and largely devoted to agriculture, being highly cultivated. As but few areas are wooded, the river is more or less flashy.

TABLE 1.—TEMPERATURE CONDITIONS AT COLUMBUS, OHIO.

| | | Degrees Fahr. |
|---|---|---|
| Mean annual | 1879-1907 | 52.1 |
| Warmest summer | June, July, Aug., 1901 | 76.0 |
| Coolest summer | June, July, Aug., 1882 | 70.1 |
| Mildest winter | Dec., Jan., Feb., 1889-1890 | 41.4 |
| Coldest winter | Dec., Jan., Feb., 1903-1904 | 23.4 |
| Warmest month | July, 1901 | 79.9 |
| Coldest month | Jan., 1893 | 18.8 |
| Highest recorded observation, once in | 1901 | 104.0 |
| Lowest recorded observation, once each, in | 1879, 1884, 1899 | −20.0 |

TABLE 2.—PERIODS OF SEVERE WINTER WEATHER AT COLUMBUS, OHIO.
Temperature Given in Degrees, Fahrenheit.

| Winter of: | CONSECUTIVE NUMBER OF DAYS THAT MEAN DAILY TEMPERATURE WAS: | | | | |
|---|---|---|---|---|---|
| | 32° or below. | 20° or below. | 10° or below. | 0° or below. | −10° or below. |
| 1878-1879 | 38 | 8-6-2-2 | 4-4-1 | 3 | .... |
| 1894-1895 | 30 | 2-7-10 | 1-6-1 | 1 | .... |
| 1904-1905 | 29 | 3-3-7-2-4-1 | 2-2-3 | 2 | .... |
| 1901-1902 | 27 | 2-4-4-4-3 | 3 | .... | .... |
| 1880-1881 | 27 | 6-1-3 | 5-1 | 2 | .... |
| 1892-1893 | 24 | 6-12 | 8-2 | 1 | .... |
| 1891-1892 | 23 | 1-1-2-2-3 | 1 | .... | .... |
| 1886-1887 | 20 | 3-4-3-2 | 2-2-2 | .... | .... |
| 1884-1885 | 18 | 5-8 | 2-7 | 1-1 | .... |
| 1884-1885 | 18 | 7-5-1 | 2-2-2 | .... | .... |
| 1896-1897 | 14 | 8 | 5 | 2 | .... |
| 1898-1899 | 13 | 10 | 7 | 4 | 2 |
| 1883-1884 | 13 | 2-2-3 | 1-2 | 1 | .... |
| 1885-1886 | 11 | 9 | 5 | 3 | .... |
| 1883-1884 | 11 | 7 | 5 | 2 | .... |

Throughout the water-shed the rock is limestone, and is covered by drift of varying thickness, although at many places it is exposed. The water is hard, carrying considerable amounts of the carbonates and sulphates of lime and magnesia, and it is highly turbid during freshets. The river, to a certain degree, is polluted, although not as

much so as other rivers flowing through more thickly populated districts, but the drainage which it receives from small cities, villages, and public institutions is sufficient to render it unfit for use as a public water supply without purification.

TABLE 3.—POPULATION ON THE WATER-SHED OF THE SCIOTO RIVER.
Drainage Area at Columbus, 1 050 sq. miles.

| | POPULATION: | | |
|---|---|---|---|
| | 1890. | 1900. | 1908. |
| Total population, towns having more than 4 000 inhabitants | 13 330 | 18 030 | 21 790 |
| Places having from 1 000 to 4 000 inhabitants | 4 220 | 4 690 | 8 450 |
| Rural population (being all the remainder) | 45 260 | 46 280 | 42 900 |
| Total population on water-shed | 62 810 | 69 000 | 73 140 |
| Population per square mile, towns having more than 4 000 inhabitants | 12.7 | 17.2 | 20.8 |
| Places having from 1 000 to 4 000 inhabitants | 4.0 | 4.5 | 8.0 |
| Rural population per square mile | 43.1 | 44.0 | 40.9 |
| Total population per square mile | 59.8 | 65.7 | 69.7 |

Table 3 gives the population on the water-shed of the Scioto above Columbus for the years 1890 and 1900, and the estimated population in 1908, made up from figures compiled by Paul Hansen, Assoc. M. Am. Soc. C. E., Assistant Engineer, Ohio State Board of Health, from which it will be noticed that the population is largely rural.

TABLE 4.—DEATH RATES IN COLUMBUS, OHIO.

| Year. | Population. | Total deaths from all causes. | Total deaths per 100 000 population. | Deaths from typhoid fever. | Deaths from typhoid fever per 100 000 population. |
|---|---|---|---|---|---|
| 1898 | 116 000 | 1 390 | 1 200 | 33 | 28 |
| 1899 | 120 000 | 1 622 | 1 350 | 31 | 26 |
| 1900 | 125 600 | 1 776 | 1 410 | 53 | 42 |
| 1901 | 131 000 | 1 551 | 1 190 | 47 | 36 |
| 1902 | 136 500 | 1 578 | 1 150 | 44 | 32 |
| 1903 | 142 000 | 1 787 | 1 260 | 46 | 32 |
| 1904 | 148 000 | 2 080 | 1 410 | 195 | 132 |
| 1905 | 155 000 | 1 899 | 1 220 | 109 | 70 |
| 1906 | 162 500 | 2 033 | 1 250 | 52 | 32 |
| 1907 | 170 000 | 2 117 | 1 250 | 48 | 28 |
| 1908 | 178 000 | 2 156 | 1 210 | 170 | 96 |
| 1909 | 186 500 | 1 039* | .... | 5* | ... |

* For first six months only.

*Death Rates.*—Table 4, also compiled by Mr. Hansen, gives the total death rates and the death rates from typhoid fever in Columbus for the ten years prior to 1908 and the rates for 1908, during the latter part of which year the water purification works were placed in operation; also the total deaths and deaths from typhoid fever for the first six months of 1909. The typhoid death rates in several of the years indicate only too clearly that purification of the water supply was needed, and that the rates in the other years were not higher is probably due to the fact that a large percentage of the water was obtained from underground sources.

## I.—THE IMPROVED WATER-WORKS.

*Historical.*—The water supply of Columbus was formerly obtained mainly from ground-water sources. The first works were situated on the east bank of the Olentangy River, just above its junction with the Scioto. The supply was obtained from a well, 20 ft. in diameter, and from a brick filtering gallery, 256 ft. in length, adjacent to which was built what is known as the West Side Pumping Station, the works being first put in operation on May 1st, 1871. The city then, as at present, was supplied by direct pumping service. No distribution reservoirs or stand-pipes were provided; reservoirs, however, were entirely out of the question on account of the topography of the city and the surrounding country.

From time to time the ground-water source of supply was increased by extending the filtering galleries and conduit systems under and along the Olentangy and Scioto Rivers, until a total length of 13 097 ft. of brick and iron conduit, 42 in. in diameter, had been provided.

The most recent extension to the conduit system was made in 1897 and 1898, when an additional 3 000 ft. of 42-in. cast-iron pipe were laid. At the time this new conduit was built, 37 tubular wells, 6 in. in diameter, were sunk along its line at depths varying from 20 to 58 ft. below its bottom, most of them, when they were drilled, being flowing wells at the conduit elevation. The laying of this additional conduit was undertaken as a precautionary measure, to provide a duplicate system for use in case of failure of the old brick conduit, warning that a collapse was likely to occur having been given by the caving in of the old conduit at several points near its upper end. The extension of the underground source of supply did not keep pace with the increasing consumption, and, each year since the works were first

PLATE VII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

FIG. 1.—VIEW OF DAM, DURING CONSTRUCTION.

FIG. 2.—VIEW OF FINISHED DAM, FROM EAST BANK.

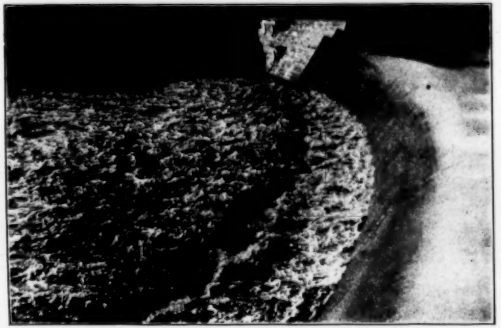


FIG. 3.—VIEW OF DAM, FROM EAST EMBANKMENT.
(5 ft. of Water on the Crest.)

FIG. 4.—VIEW OF SCIOTO RIVER PUMPING STATION AND WATER PURIFICATION WORKS.

established, more or less water was obtained directly from the Olentangy and Scioto Rivers, in the last few years, however, only from the Scioto.

In 1889, it having been considered that the underground sources of supply tributary to the West Side Pumping Station had been developed to as great an extent as was profitable, attention was turned to Alum Creek, the stream flowing along the eastern boundary of the city. A second pumping station, known as the East Side Pumping Station, was built on the west bank of the creek, and pumping was begun on May 5th, 1891, from a brick well, 25 ft. in diameter, and from 32 tubular wells, 6 in. in diameter and from 60 to 65 ft. in depth. As was the case at the West Side Pumping Station, the supply from the underground sources at times was insufficient and was augmented by drawing directly from Alum Creek.

The construction of a storage reservoir on the Scioto River first received consideration in 1879. In 1886 plans for a low dam across the river were prepared by Mr. John B. Gregory, but the cost of the proposed undertaking was so large that the project was laid aside in favor of additional filtering galleries. In 1893 the project was again revived, when a storage reservoir was reported as necessary by Rudolph Hering, M. Am. Soc. C. E., he favoring the Scioto River as being a better source of supply than other available streams.

It was not until 1897, however, that definite steps were taken to secure an additional supply. Extended surveys and studies were then made by Julian Griggs, M. Am. Soc. C. E., Chief Engineer of the Department of Public Improvements, and early in 1898 Mr. Griggs recommended the construction of a curved concrete overflow dam, 30 ft. high, across the Scioto River, about 5.5 miles northwest of the West Side Pumping Station. In the spring of the same year, general plans of the proposed work were submitted to the Ohio State Board of Health, and in their approval a recommendation was made that the height of the dam be increased from 30 ft. to 50 ft., as a much greater storage could thereby be provided.

In June, 1898, the whole subject was reviewed by James D. Schuyler, M. Am. Soc. C. E., Consulting Engineer, and in July of the same year, he endorsed the proposed construction and concurred in the recommendation that the 50-ft. dam be built. In the course of the next two years several attempts were made to begin the construction, but, owing to legal and other difficulties, they were unsuccessful.

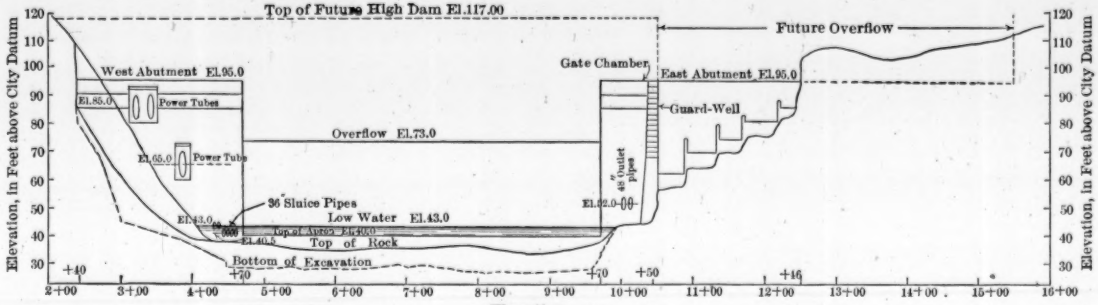
In 1900 the question of an additional supply was again taken up, and Samuel M. Gray, M. Am. Soc. C. E., Consulting Engineer, was asked to report, not only on the additional supply, but also on the improvement and extension of the whole water-works system. In the report submitted by Mr. Gray, in February, 1901, he endorsed the previous recommendation that the Scioto River be adopted as a source of supply and that a masonry dam 52 ft. high and an impounding reservoir be built. He advised also that water purification works, consisting of a softening and mechanical filtration plant, be built adjacent to the West Side Pumping Station, that a gravity conduit be laid from the storage reservoir to the purification works, that the East and West Side Pumping Stations be abandoned, that a new pumping station with entirely new equipment be built, and that the distribution system be revised and reinforced.

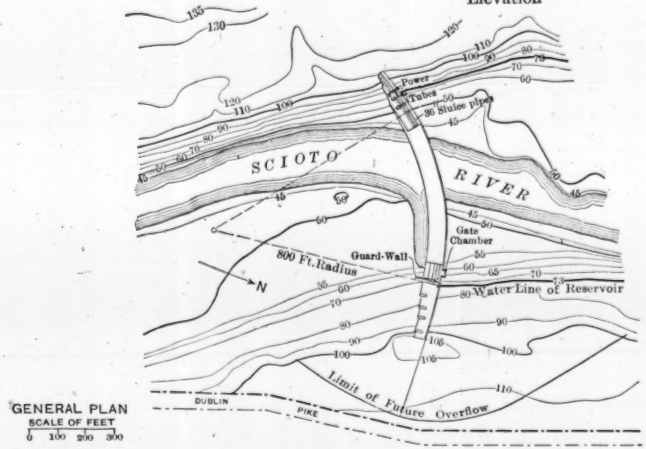
Following the presentation of Mr. Gray's report, steps were taken to inaugurate the construction of the work outlined and recommended by him, but it was not until 1904 that the necessary funds were appropriated and the work of construction commenced.

*Brief Outline of the New Works.*—In the development of the new works, the scheme outlined in Mr. Gray's report has in general been followed, but modifications have been made where further study indicated that it would be desirable. Briefly stated, a masonry dam, raising the water level 30 ft., and a storage reservoir, have been built on the Scioto River, about 5.5 miles northwest of the old West Side Pumping Station. About 4.5 miles below the dam a new pumping station and a purification works have been built. No appropriation for the gravity conduit was made, and therefore the river is used as a conduit, the water flowing down the river from the dam to the new pumping station. The water is here raised by low-lift pumps to the purification works, is softened and filtered, and then pumped from the new station through two 36-in. force mains connecting with the distribution system in the city. The old East Side and West Side Pumping Stations are no longer in service, the work which they formerly did being now performed by the new pumping station. The location of the new works relative to the city is shown on Fig. 1.

## THE SCIOTO RIVER STORAGE DAM AND RESERVOIR.

*Type of Structure.*—The Scioto River Storage Dam, as it is officially known, is a concrete structure about 1 006 ft. long, consisting of




GENERAL PLAN
SCALE OF FEET
0 100 200 300

## SCIOTO RIVER STORAGE DAM
### GENERAL PLAN AND ELEVATION

FIG. 3.

two abutment sections, one on each bank of the river, with an overflow or rollway section between. The dam is of the curved or arched type, with the convex side up stream, the vertical up-stream face for a length of 810 ft. being built in plan to a radius of 800 ft.

In Mr. Gray's report it was recommended that a 52-ft. dam, or so-called high dam, be built, that is, a dam which would raise the water level 52 ft., but, owing to reasons purely local, and having no relation to the design of the structure, the 30-ft. or low dam was built. The foundations and abutment sections, however, have been constructed so that at a future date the dam can be raised 22 ft. to the full height recommended. Fig. 3 is a general plan and elevation of the dam.

The crest of the present overflow is at Elevation 73.0, or 30 ft. above former mean low water, the abutment sections on either side rising to Elevation 95.0, or 22 ft. above the crest of the overflow. With the high dam, the crest of the future overflow would be at Elevation 95.0 and the top of the abutment section at Elevation 117.0.

*Profile of Dam.*—The profile of the dam as adopted is substantially that of the 52-ft. dam recommended by Mr. Gray, a few slight changes in the dimensions, however, having been made in order to secure a somewhat smoother outline. Although the dam is of the curved type, it has a gravity section, and in the design no consideration was given to the effect of any possible arch action.

The factors controlling the design of the profile are discussed so fully in Mr. Gray's report that they will not be considered here at length, it being sufficient to state that, in addition to the water pressure on the back of the dam, allowance was made for an upward water pressure equal to two-thirds of the head at the back of the dam and decreasing uniformly to the toe, and for an ice thrust of 34 000 lb. per lin. ft. of dam applied at the crest of the future overflow, or 22 ft. below the top of the high dam. In all the computations relating to the stability of the dam, the weight of the concrete was assumed as 140 lb. per cu. ft.

Two profiles of the 52-ft. dam are shown, Fig. 4, giving the lines of pressure when the reservoir is full and empty, and Fig. 5, giving the lines when the reservoir is filled to 22 ft. below the top, that is, to the crest of the future overflow.

By reference to Fig. 4 it will be seen that with the reservoir empty, or with the reservoir full and water pressure only on the back of the

dam, the lines of pressure fall inside the middle-third limit. With the reservoir full and with upward water pressure on the base of the dam, the line of pressure falls outside the middle-third limit. As the condi-

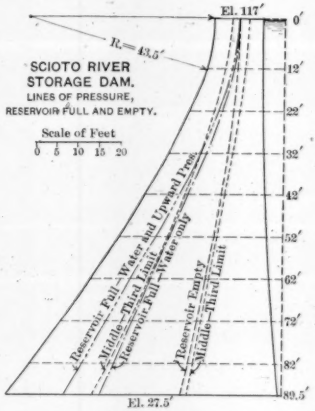



FIG. 4

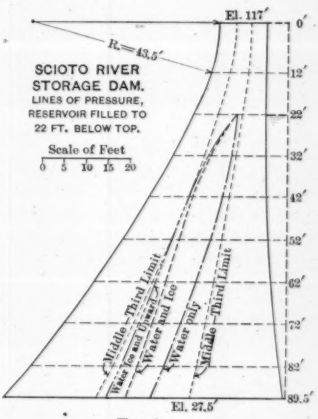



FIG. 5

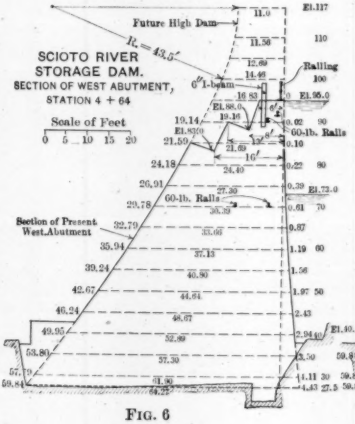



FIG. 6

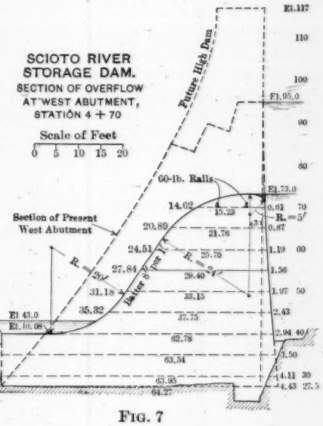



FIG. 7

tion of a full reservoir and of an upward water pressure of the amount assumed would occur so infrequently, and especially as the duration of the period when the reservoir would be full would be only a few

hours, and, further, as it would probably require several days for the upward pressure to equal the amount assumed, the increase in section necessary to bring the line of pressure inside the middle-third limit was not considered warranted.

With the reservoir filled to the crest of the future overflow, it will be seen, by referring to Fig. 5, that the lines of pressure due to water pressure only, to water pressure and ice thrust, and to water pressure, ice thrust, and upward pressure, all fall inside the middle-third limit.

*West Abutment.*—The section of the present west abutment is shown by the full lines in Fig. 6; the dotted lines indicate what the full section of the west abutment will be when the dam is raised 22 ft. At the top of the present section steps have been left for the purpose of providing a bond with future work. In addition to the steps, 6-in. I-beams, 10 ft. long and 5 ft. apart, have been built into the masonry to provide an additional bond between the old and new work.

Inasmuch as it is probably only a question of time until the dam will be raised, no attempt at architectural ornamentation was made, that being left to be considered with future construction.

*Present Overflow.*—The present overflow has a rollway section with an apron extending out a few feet at the toe, as shown in Fig. 7. Superimposed on this section are shown the sections of the present and future west abutments. The overflow is 500 ft. long, and was designed to discharge a maximum rainfall of 6 in., on the drainage area of 1 032 sq. miles above the dam, flowing off in 24 hours, or about 166 500 cu. ft. per sec. To discharge this quantity would require a depth of about 21.7 ft. on the overflow. In the flood of March, 1898, the greatest of which any records are available, the maximum discharge of the river was estimated at about 50 000 cu. ft. per sec. A depth of only about 10 ft. on the overflow would be required to pass this quantity of water. Owing to its length, the possible depth of water flowing over it, and the possibility of raising the dam, it was not considered advisable to attempt to bridge the overflow. When the dam is raised, the present overflow will become a part of the west abutment, and especial care will have to be taken to insure a satisfactory bond between the old work and the new. In all probability some method of steel reinforcement will be required.

*36-in. Sluice-Pipes.*—In order to care for the ordinary flow of the river during construction, six lines of 36-in. cast-iron pipe were built

through the west abutment of the dam, the up-stream end of each being provided with a 36-in. circular sluice-gate. In case it should ever be desired to drain the reservoir to the lowest possible point, these gates could be used for this purpose, but, under ordinary conditions, they will remain closed.

*Power Tubes.*—It was pointed out in Mr. Gray's report that, with the 52-ft. dam, a considerable amount of water-power could be developed at the dam from the water overflowing in excess of that required by the city. In order to provide for the possible future development of this power, should the present dam be raised, three so-called power tubes have been built into the west abutment, two at Elevation 85.0 and one at Elevation 65.0, for connecting with future penstocks. Each tube is a riveted steel pipe, 9 ft. in diameter and $\frac{5}{16}$ in. thick, reinforced with bent steel angles placed circumferentially. Reinforced concrete bulkheads have been built in the ends of each tube, and on the up-stream ends heavy flanges have been provided to which gate-frames, screens, or other construction can be bolted.

*Gate-Chamber.*—The gate-chamber is just east of the present overflow and on the up-stream side of the present east abutment. No superstructure has been provided in the present construction, as it would be necessary to remove it, should the dam be raised. Instead, an operating-room has been built in the upper part of the gate-chamber, with its roof flush with the top of the present east abutment. Should the dam be raised, the roof only would be removed, thereby permitting the gate-chamber to be extended up to the top of the high dam. A gate-house, or an operating-room similar to the present design, could then be built, as desired. The floor of the operating-room is at Elevation 84.0, or 11 ft. above the crest of the overflow, and would not be flooded except for a short time during a period of very high water, in fact, higher than that of the flood of March, 1898. A manhole in the roof and a ladder extending to the floor below furnish access to the operating-room.

Below the operating-room, the wells are in duplicate, water being admitted through openings in the up-stream face of the gate-chamber. In each up-stream well two 36 by 60-in. Coffin sluice-gates have been provided, permitting water to be drawn at different levels. An additional sluice-gate of the same size, at a higher elevation, will be added should the dam be raised. Three sets of grooves for stop-planks and

screens have also been provided. In each down-stream well is placed a 48-in. circular sluice-gate, each connecting directly with a line of 48-in. cast-iron pipe extending through the dam. These two lines of 48-in. pipe will connect with the future conduit from the dam to the water purification works.

As mentioned before, this conduit has not been built. Under ordinary conditions, the reservoir is full and the entire flow of the river passes over the overflow and thence down to the purification works, where a portion of it is pumped to the settling basins. When the amount taken by the purification works is in excess of the flow of the river, however, the deficit is made up by drawing from the storage in the reservoir, the water being drawn through the gate-chamber and discharged again into the river just below the dam. Under such conditions, fine screening at the gate-chamber would be useless, and hence coarse screens only have been provided, sufficient to keep out floating brush and logs from the wells.

These coarse screens at present extend from the bottom of the gate-chamber up to about the level of the crest of the overflow; above them are placed stop-plank gates reaching to the floor of the operating-room. The twelve screens consist of $3\frac{1}{2}$ by $\frac{3}{8}$-in. flat steel bars, 4 in. from center to center, held in steel frames 3 ft. 11 in. high and about 4 ft. 9 in. wide. The four stop-plank gates are 3 in. thick, and are made up and bolted together in sets, 4 ft. 2 in. high and 4 ft. 9 in. wide. The stop-plank gates and screens are raised or lowered by a traveling screen lifter, moving up or down in the grooves, and hung from a triplex block.

*Future Overflow.*—The future overflow is located at the east end of the dam, and at present that portion which has been built forms the east abutment of the dam. It has a roll-way section, the down-stream face having the same outline as the present overflow, as shown in Fig. 8. The present construction has a length of 196 ft. In

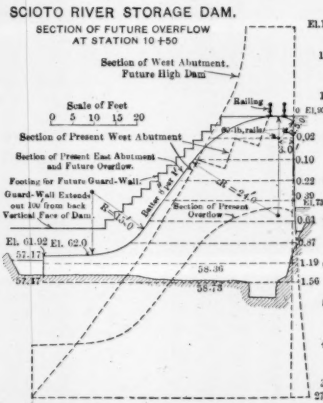
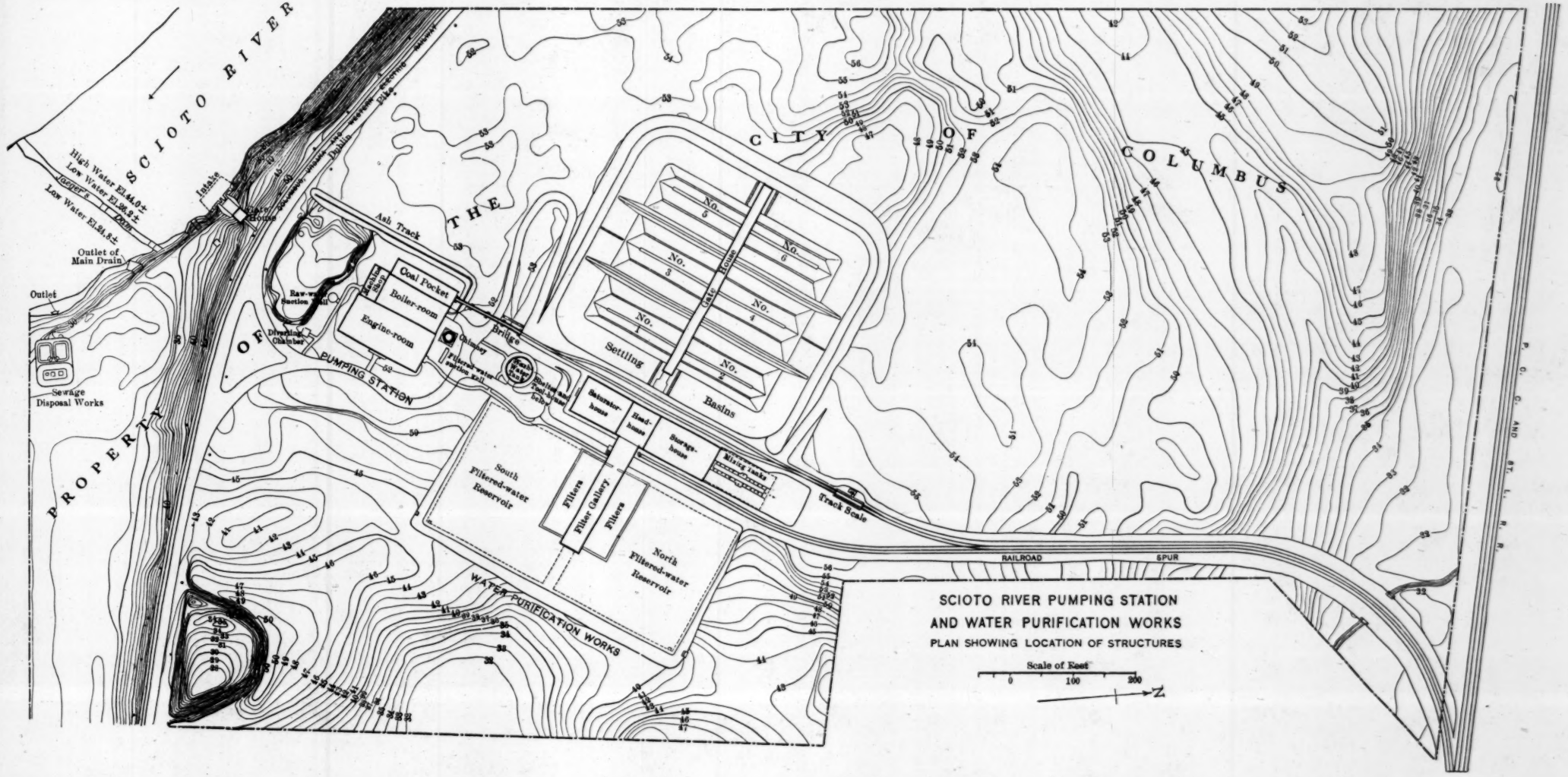



FIG. 8.

PLATE VIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



order to provide an overflow 500 ft. in length, the remaining 304 ft. will be excavated in rock. On the down-stream side, four guide-walls have been built in order to prevent lateral movement of the water immediately at the foot of the rollway. A guard-wall, backed up with earth, will also be built, extending out about 100 ft. from the back vertical face of the dam. The foundation and footing for this future guard-wall have been built with the present construction.

*Foundation.*—The foundation on which the dam is built is Columbus limestone, the depth of the excavation being governed largely by the character of the rock. Under the overflow section, the rock was excavated to a depth sufficient to protect the foundation from the action of water moving at a high velocity, the rock here being hard, and free from clay pockets; seams, however, were found at various angles. Under the west abutment, between Elevations 53.0 and 62.0, the rock was softer than that either above or below, and some large vertical cracks, filled with clay and extending back into the hillside, were found. The excavation, therefore, was carried to greater depths than was contemplated originally. The stratum of softer rock was also found on the east bank.

A cut-off trench, varying in depth from 3 to 5 ft. and about 5.5 ft. wide, was excavated under the up-stream portion of the dam. A part of the trench was excavated by a drill mounted on a horizontal bar, light charges of powder being used to loosen the rock, but satisfactory results were not obtained until an Ingersoll-Sergeant channeling machine was installed.

*Concrete.*—The dam was built mainly of concrete, but large stones were bedded in it to a certain extent, the percentage of such stones in the whole, however, being small. Lehigh Portland cement was used throughout the work, and was furnished to the contractor by the City. The ballast for the concrete was crushed limestone screened into three sizes: No. 1, 0.25 to 0.75 in.; No. 2, 0.75 to 1.5 in.; and No. 3, 1.5 to 3 in.

During the fall of 1904, when about 6 300 cu. yd. of concrete were placed, the materials were mixed in the proportion of 1 volume of cement, 3 volumes of sand, and 2 volumes each of Nos. 1, 2, and 3 ballast. During 1905, when the remainder of the concrete was placed, the proportions were changed to 1 of cement, 2.71 of sand and 2.29 of each of the three grades of ballast. The two mixtures above mentioned were used in the main body of the dam. On the face of the present

and future overflows, and on the vertical sides of the abutment sections next to the present overflow, for a depth of 1 ft., and on the top of the abutment sections, for a depth of 6 in., a richer mixture was used, the concrete containing 50% more cement than that in the main body of the dam.

The total volume of concrete placed in the dam was 56 330 cu. yd., in which 56 870 bbl. of cement were used, giving a ratio of 1.01 bbl. of cement per cubic yard of concrete, and agreeing almost exactly with the specifications, which stated that "in general, not less than one barrel of cement will be used in each cubic yard of concrete."

*Reservoir.*—The reservoir formed by the construction of the dam is peculiar in shape, as it is very long and narrow, the total length being about 5.8 miles and the mean surface width about 516 ft.; the maximum width is about 820 ft., and the minimum about 200 ft. The area of the water surface is about 363 acres, and the mean depth about 14.5 ft.; the maximum depth, about 35 ft., is just above the dam. The total volume of water impounded by the present or 30-ft. dam, up to Elevation 73.0, is 1 720 000 000 gal., of which 1 487 000 000 gal. are available, taking low water at Elevation 55.0. The total volume which would be impounded by the 52-ft. dam would be 5 681 000 000 gal., of which 5 448 000 000 gal. would be available.

Inasmuch as the water was to be purified by filtration, it was not considered necessary to strip the surface of the reservoir. All trees were cut down, and all stumps and roots 1 in. or more in diameter were grubbed out to a depth of at least 1 ft. below the surface, after which the material was burned. The surface of the ground was then burned over. There were a few buildings on the site of the reservoir, one of which would have been submerged. Some of these buildings were moved to higher ground; the others were burned or torn down. One old bridge was removed, and a new one, 540 ft. in length, was built to replace it. The new bridge was designed and erected under the direction of Mr. Walter Braun, County Surveyor, the City paying 70% of the cost. In addition to the above, about 3.9 miles of roads were relocated and constructed.

*Cost.*—Table 5 gives the cost of the reservoir and dam, and Table 6 gives the cost per million gallons of capacity. In order that the figures may be understood clearly, one or two items need explanation. In the reconstruction of the bridge and the approaches, as previously stated,

the City bore 70% of the cost, but the figures in Tables 5 and 6 give the total costs, and not the proportionate part paid by the City. Similarly, the figures given for the cost of engineering include the cost of engineering chargeable to the bridge, although this work was not done under the direction of the City.

TABLE 5.—Cost of Scioto River Storage Reservoir and Dam.

| | | | | | | |
|---|---|---|---|---|---|---|
| *Reservoir.* | | | | | | |
| Land | 452 | acres | @ | $334 | | $150 850 |
| Clearing and grubbing | 256 | acres | @ | 79 | | 20 200 |
| Moving buildings | | | | | | 2 440 |
| Reconstruction of roads | 3.9 | miles | @ | 12 670 | | 49 400 |
| Reconstruction of bridge | | | | | | 65 800 |
| Convenience stations | 2 | ..... | @ | 880 | | 1 760 |
| Keeper's house, repairs, and grading | | | | | | 1 760 |
| Total cost of reservoir | | | | | | $292 210 |
| *Dam.* | | | | | | |
| Excavation. | | | | | | |
| Dry earth | 10 850 | cu. yd. | @ | $0.40 | $4 340 | |
| Wet earth | 5 330 | cu. yd. | @ | 0.80 | 4 270 | |
| Rock | 29 900 | cu. yd. | @ | 1.50 | 44 870 | $53 480 |
| Masonry and steel. | | | | | | |
| Concrete | 55 710 | cu. yd. | @ | $4.94 | $275 340 | |
| Steel rails and splices | 28.7 | tons | @ | 35.00 | 1 000 | |
| Structural steel | 11 460 | lb. | @ | 0.045 | 520 | 276 860 |
| Gate chamber. | | | | | | |
| Concrete | 620 | cu. yd. | @ | $4.94 | $3 060 | |
| Steel and cast iron | 18 430 | lb. | @ | 0.045 | 820 | |
| 48-in. sluice-gates | 2 | ..... | @ | 600.00 | 1 200 | |
| 36 by 60-in. sluice-gates | 4 | ..... | @ | 600.00 | 2 400 | |
| 48-in. cast-iron pipe | 28.5 | tons | @ | 26.84 | 770 | |
| Screens, stop-planks and lifters | | | | | 580 | 8 830 |
| 36 in. sluice-pipes. | | | | | | |
| Steel and cast iron | 5 270 | lb. | @ | $0.042 | $220 | |
| 36-in. sluice gates | 6 | ..... | @ | 263.00 | 1 580 | |
| 36-in. cast-iron pipe | 65.3 | tons | @ | 24.96 | 1 630 | 3 430 |
| Power tubes | 3. | | | | | 3 640 |
| Railing | 1 000 | lin. ft. | @ | 1.75 | ..... | 1 750 |
| Total cost of dam | | | | | | $347 990 |

Summary.

| | |
|---|---|
| Reservoir | $292 210 |
| Dam | 347 990 |
| | $640 200 |
| Total cost of construction, exclusive of land | $489 350 |
| Engineering. | |
| Pay-roll | $27 540 |
| Supplies | 3 560 |
| Expenses | 2 230 $33 330 |
| Percentage for engineering | 6.81 |

The item for engineering needs further explanation. Prior to 1904, when the engineering force was organized for carrying on the work

of construction, and extending over a series of years during which the preliminary studies of the dam, the surveys of the reservoir, and exploration of the dam site were made, no separate account was kept of the cost of engineering, it being included in the general engineering expenses of the City. After the writer became connected with the work, he made an attempt to ascertain this preliminary cost, but was unable to do so. The cost of engineering given in Tables 5 and 6, therefore, does not include this preliminary work, but does include the preparation of all the contract drawings and specifications, and the engineering expenses during the full period of construction.

TABLE 6.—COST, PER MILLION GALLONS, OF SCIOTO RIVER STORAGE RESERVOIR AND DAM.

| Items. | Total cost. | Cost, per Million Gallons. | |
|---|---|---|---|
| | | Total capacity, 1 720 000 000 gal. | Available capacity, 1 487 000 000 gal. |
| Land | $150 850 | $88 | $101 |
| Reservoir, exclusive of land | 141 360 | 82 | 95 |
| Dam | 347 990 | 202 | 234 |
| Total, exclusive of engineering | $640 200 | $372 | $430 |
| Engineering | 33 330 | 19 | 22 |
| Total | $673 530 | $391 | $452 |

*Contractors, and Progress of Work.*—The preparation of the drawings and specifications was begun in January, 1904. The main construction work was practically completed by December, 1905, although some work of minor importance was done in 1906. The principal contracts for the work were:

Dam..... James Westwater.
Cement..... The Kelley Island Lime and Transport Company.
Sluice-gates..... Coffin Valve Company, and The Michigan Brass and Iron Works.
Clearing and grubbing... Hoover and Kinnear.
Roads..... James Westwater, and The Buckeye Engineering and Construction Company.
Bridge..... Mt. Vernon Bridge Company.

## THE SCIOTO RIVER PUMPING STATION AND WATER PURIFICATION WORKS.

The Scioto River pumping station and water purification works are located on the high ground on the north bank of the Scioto River, about 4.5 miles below the storage dam and about 1 mile above the old West Side Pumping Station. Plate VIII is a general plan of the works, and on Plate IX is shown more in detail the arrangement of the several structures and the layout of the various conduits and pipe lines.

Briefly stated, the operation of the works is as follows: The raw water is drawn from the river through an intake and intake conduit to a raw-water suction well just south of the pumping station. From this well the water is pumped by low-lift pumps to the purification works where it is softened and filtered, passing finally through the filtered-water reservoirs and back to a filtered-water suction well just north of the pumping station. From this well the water is pumped by direct-service pumping machinery through two lines of 36-in. cast-iron pipe, about 4 900 ft. in length, to a point opposite the old West Side Pumping Station where connections are made with the existing distribution system.

*Capacity of Works.*—The pumping station and purification works are designed for extension to an ultimate net normal capacity of 40 000 000 gal. per 24 hours. At present the pumping station has a net normal capacity of 20 000 000 gal. per 24 hours, but the building is of sufficient size for equipment having the ultimate net normal capacity. The purification works at present have a net normal capacity of 30 000 000 gal. per 24 hours, but have been arranged so that extensions may readily be made.

### Minor Structures.

*Intake, Gate-House, and Intake Conduit.*—The intake, on the river bank, consists of a low concrete head-wall provided with coarse screens, through which water is admitted to two 4-ft. concrete conduits connecting with the screen-wells in the gate-chamber. Passing through a double set of fine brass screens, 4 meshes per in., the water flows through a 5-ft. reinforced concrete intake conduit to the raw-water suction well. The gate-chamber is surmounted by a small brick gate-house, 17 ft. 4 in. square, in which are located the operating stands for controlling the sluice-gates and also a small hand traveling crane with an electric hoist for raising and lowering the screens and stop-planks.

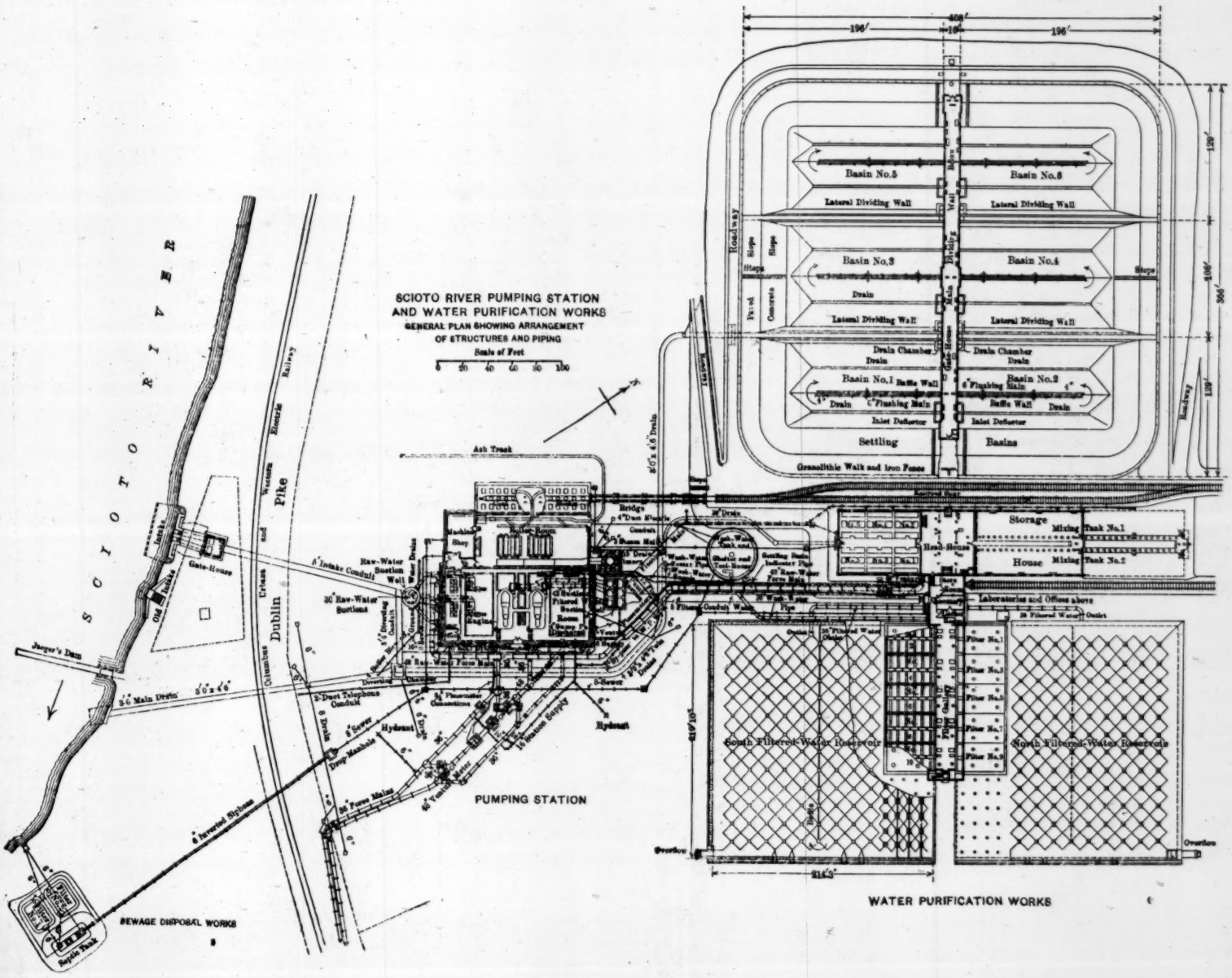
*Raw-Water Suction Well, and Diverting Chamber.*—The raw-water suction well is a circular concrete structure, 13 ft. in diameter inside and 34 ft. deep. From the well to the pumping station three 30-in. cast-iron suction pipes have been laid, but at present only two of them have been arranged to supply water to the low-lift pumping machinery. The level of the water in the suction well is shown by an indicator in the basement of the engine-room.

Connected with this well, also, are two lines of 24-in. perforated cast-iron pipe, each 24 ft. in length and located parallel to the south wall of the engine-room. These pipes are perforated with 1½-in. holes, 4 in. apart on centers, and are surrounded by layers of gravel screened to three different sizes. Under ordinary conditions, with low stages of water in the river, the sluice-gates on the inner ends of these pipes are closed, but, during periods of high water, it is possible to throttle the supply from the river and to open these gates and admit ground-water, the object being to lower the ground-water level as much as possible and thereby relieve, to a certain extent, the water pressure on the pipe gullets in the basement of the engine-room.

By reference to Plate IX it will be seen that a drain from the settling basins passes down the east side of the pumping station and through a so-called diverting chamber. A 3 ft. 6-in. concrete diverting conduit connects the diverting chamber with the raw-water suction well. When one of the settling basins is drained for cleaning, the upper 10 or 12 ft. of water, which has been softened and settled, can be first drawn off, passing down the settling-basin drain and through the diverting chamber and diverting conduit to the raw-water suction well, from which it can be pumped back to the other compartments of the settling basins. The water remaining in the settling basin is then drained to the river. An overflow weir has been provided in the diverting chamber so that if the basin when full should be drained accidentally, before the gates in the diverting chamber are properly set, the water would be discharged over this weir and through the main drain to the river, thereby preventing the flooding of the grounds, the capacity of the weir being in excess of that of the settling-basin drain.

*Filtered-Water Suction Well.*—The filtered-water suction well is a rectangular concrete structure, 15 ft. wide, 24 ft. long, and 26 ft. 6 in. deep, divided into three separate wells, a 42-in. cast-iron suction pipe from each extending into the basement of the engine-room. At present

PLATE IX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



only two of the suction pipes are in service, the third being provided for a future pumping engine. Filtered water is delivered to the well, from a valve-chamber in the purification works, through a 5-ft. reinforced concrete filtered-water conduit, the valve-chamber in turn being connected with the filtered-water reservoirs by two lines of 36-in. cast-iron pipe. The suction well is tightly roofed over, but a hooded vent to the atmosphere has been provided. The water level in the well is shown by an indicator in the engine-room. A by-pass from the discharge pipes of the pumping engines connects with the suction well for the preliminary operation of the engines prior to placing them in regular service.

*Railroad Spur and Bridge.*—The pumping station and purification works are connected with the Pittsburg, Cincinnati, Chicago and St. Louis Railroad by a spur built on an embankment and terminating over the coal pocket. From the east embankment of the settling basins to the coal pocket the track is carried on a deck plate-girder bridge, 114 ft. 6 in. long, made up of four equal spans. The piers and abutments are of concrete.

*Sewage Disposal Works.*—The sewage from the pumping station and water purification works is cared for by a small disposal works on the bank of the river on the down-stream side of the low dam below the intake. As built, the works consisted of a septic tank and two intermittent sand filters. When the disposal works were designed it was known that they would be flooded by high water in the river, but it was expected that the damage could easily be repaired. The unusually high flood in the winter of 1908-09, however, demonstrated that it would be better not to attempt to repair the filters each time they might be damaged, and their use has been abandoned. In lieu of operating the filters, it is proposed to sterilize the effluent from the tank before discharging it into the river.

## The Pumping Station.

### Building.

*Construction of Building.*—The pumping station building, a plan and section of which are shown on Plates X and XI, covers an area of 147 ft. 6 in. by 152 ft. 8 in., and includes an engine-room, boiler-room, coal pocket, coal and ash tunnel, store-room, machine-shop, lavatory,

locker-room, and office. The substructure, throughout, is of concrete, reinforced with twisted steel rods where necessary.

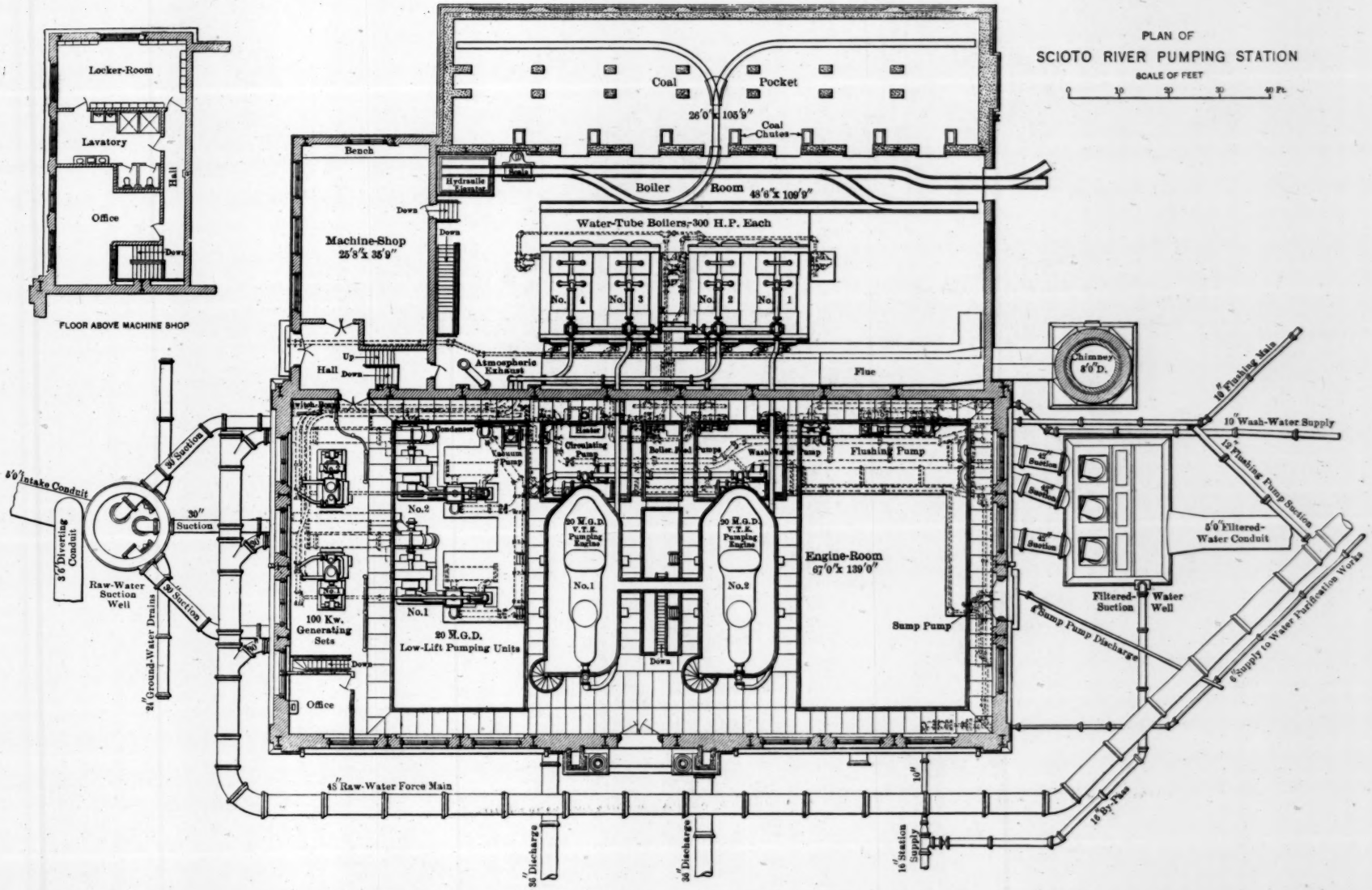
The superstructure, with the exception of the coal pocket, is of steel-frame construction, the roof trusses and crane runway girders being carried on steel columns. The walls are of brick masonry, faced outside with red pressed brick. The water-table, belt-courses, window-sills, main entrance, and similar trim, usually of cut stone, are of concrete, constructed in special moulds, with carefully finished surfaces, and present a very attractive appearance.

The engine-room roof is of slate laid on 3-in. hollow terra cotta tile supported on steel tees, which, in turn, are carried by the rafters and purlins. The under side of the tile is plastered with hard wall plaster and painted. The roof over the boiler-room and over the office, lavatory, and locker-rooms, consists of slabs of reinforced concrete, 4 in. thick, resting on the upper chords of the roof trusses and on the intermediate framing. On the concrete is laid three-ply roofing felt, bedded in hot asphalt, which in turn is protected by vitrified roofing tile, ¾ in. thick, also bedded in asphalt. Expansion joints in the concrete, flashed with corrugated copper, were made over each roof truss. The monitor over the boiler-room is of steel-frame construction, the walls being of expanded metal and plaster. The building is lighted throughout by electricity, and in the engine- and boiler-rooms, in addition to numerous incandescent lights, arc lights are used.

*Engine-Room.*—The engine-room basement is 67 ft. wide, 139 ft. long, and 17 ft. 6 in. in depth below the main gallery floor. The walls of the superstructure are set back 6¾ in. The total height of the room from the basement floor to the ridge of the roof is 91 ft. 7¾ in. The basement is floored over only at the south end for a width of about 15 ft. where a small office, the generators, and the switchboard are located. A gallery, 5 ft. wide, extends around the four sides of the room, but, in front of the pumping engines, it is widened out to cover all the space between the engines and the main entrance. The pumping engines are reached at the rear by bridges connecting with the engine-room gallery. The walls of the superstructure are faced inside with pressed brick, the wainscot, 6 ft. 6 in. high, being of red vitrified brick, and the wall above of light-buff speckled brick. A ladder provides access to the crane cab.

The basement is reached by two stairways, one between the pumping

PLATE X.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



engines and the other at the south end of the room. Under ordinary conditions, the ground-water level is some 8 ft. or more below the basement floor, and on this account, and considering the character of the construction and the expense, the floor was not water-proofed. With long-continued, extreme, high water in the river, seldom likely to occur, the ground-water might rise to such an extent as to produce an upward pressure on the floor. To provide for this condition, however, openings, protected with gratings, have been left in the floor to relieve the pressure, and equipment has been provided for pumping out water which may find its way into the basement. The walls of the basement are painted.

*Boiler-Room.*—The boiler-room is about 48 ft. 6 in. wide, 109 ft. 9 in. long, and has a clear height of 29 ft. 2 in. to the lower chords of the roof trusses. The floor in front of the boilers, over the coal and ash tunnel, is of reinforced concrete, and, between the track and the boiler fronts, it is protected with checkered cast-iron floor-plates. The industrial railway in the boiler-room is made up of cast-plate track and switches. The walls of the room are lined with hard red brick. The monitor and roof trusses were designed to carry a coal conveyor, if it should be found desirable to install one.

The coal and ash tunnel below is 17 ft. 5 in. wide and 8 ft. 6 in. high in the clear, and provides ample room for the easy loading of coal and the removal of ashes. The tunnel is reached by a stairway at the south end of the boiler-room and also by a hydraulic elevator.

*Coal Pocket.*—The coal pocket, which is all above ground, is 26 ft. wide, about 105 ft. 9 in. long, and 12 ft. high in the clear, and provides storage for 800 tons of coal, or about 40 days' supply under present conditions. The walls are of concrete. The roof is of combined steel and reinforced concrete, the track rails being carried on steel I-beams and plate girders bedded in concrete. The thrust due to starting and stopping cars is taken up by the concrete columns and side-walls and by buttresses at the ends. Openings in the roof permit of using either side- or bottom-dumping cars. Openings in the floor admit coal to the chutes.

*Machine-Shop and Rooms Above and Below.*—The machine-shop, located just south of the boiler-room, is 25 ft. 8 in. wide and 35 ft. 9 in. long, and will be fitted up for small repair work with electrically-operated machine tools. The basement below the machine-shop, 24 ft.

8 in. wide and 47 ft. 11 in. long, is used as a store-room for miscellaneous supplies. Above the machine-shop is the main office, a lavatory with sanitary conveniences and shower baths, and a locker-room furnished with expanded-metal lockers.

*Chimney.*—The chimney is of radial brick construction, 8 ft. inside diameter at the top and 165 ft. 6 in. high, above the boiler-room floor. A fire-brick lining extends up about 42 ft. above the top of the flue opening. The foundation is of concrete, cored out to save material, and extends to a depth of 26 ft. 10 in. below the boiler-room floor, or to the same depth as the foundations of the building immediately adjoining. The superstructure of the chimney was built by H. R. Heinicke, Incorporated.

Machinery and Equipment.

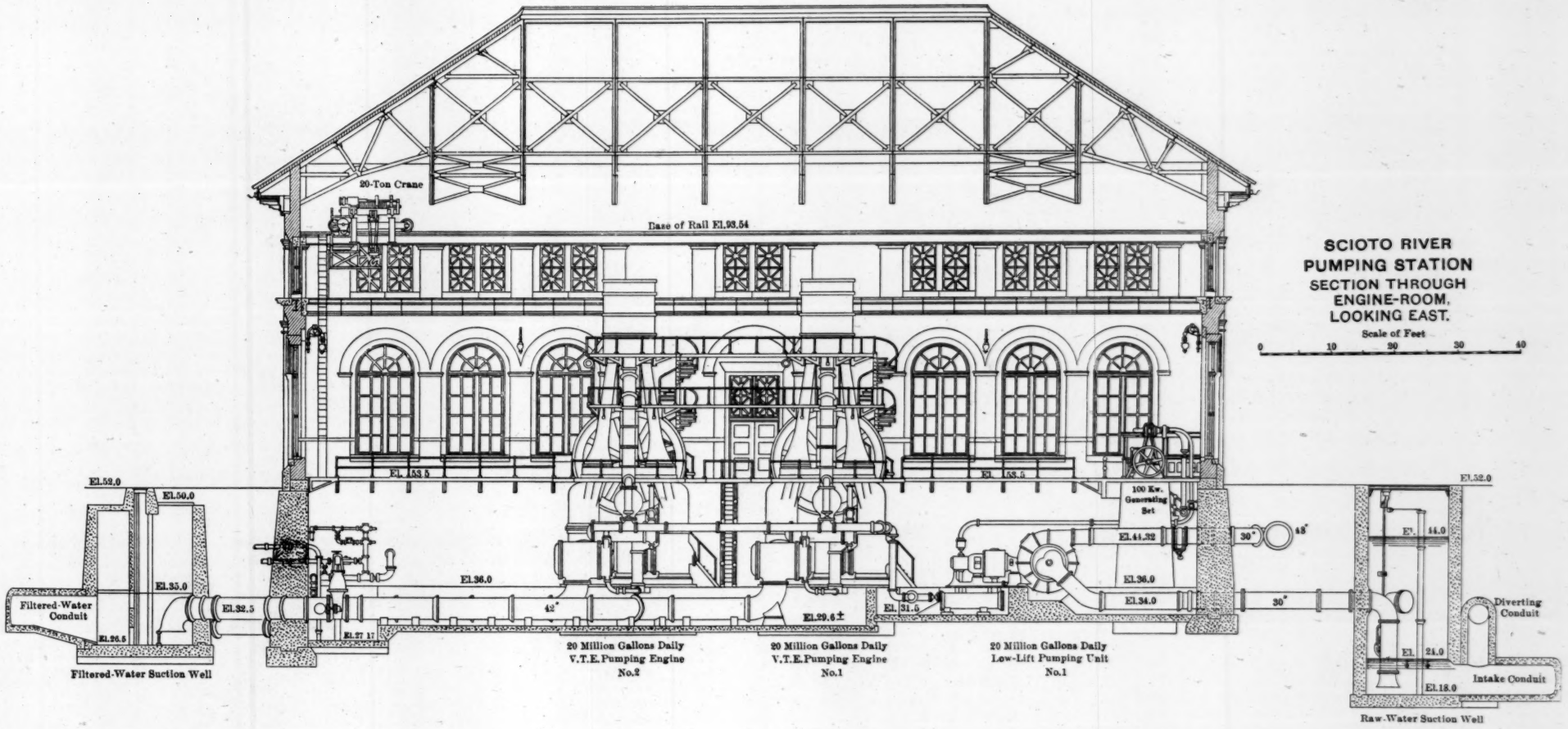
*Pumping Engines.*—For pumping filtered water to the City the present equipment includes two vertical, triple-expansion, pumping engines, built by the Holly Manufacturing Company, and operating on direct service. Space has been provided for a third engine. Each machine has a minimum capacity of 7 000 000 gal., a maximum capacity of 25 000 000 gal., and a normal capacity of 20 000 000 gal. per 24 hours, against a total head of 205 ft.

The pumping engines are of the single-A, box-frame type, the engine bed-plates being supported directly on the suction and discharge air chambers. The steam cylinders are 28, 54, and 80 in. and the water plungers 30½ in. in diameter. The stroke is 5 ft., and the piston speed 250 ft. per min. at normal capacity.

The suction pipe is 42 in. and the discharge 36 in. in diameter. Water is drawn through a surface condenser, taking the entire flow, into the suction valve-chambers, then passes through the pump cylinders and out through the discharge valve-chambers. The valve decks are vertical, of cast steel, the valves being screwed directly into the decks. An air compressor and vacuum pump is driven by the main engine, and provision has been made for the addition of a direct-connected feed pump.

*Low-Lift Pumps.*—For pumping raw water to the purification works, two low-lift pumping units have been installed, space being left for a third. Each unit consists of a single-suction, horizontal, Worthington, volute pump, with 26-in. suction and discharge nozzles, direct-connected to a 12½ and 30 by 17-in. horizontal, tandem-compound, con-

PLATE XI.
TRANS. AM. SOC CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO




## SCIOTO RIVER PUMPING STATION
### SECTION THROUGH ENGINE-ROOM, LOOKING EAST.

Scale of Feet
0 10 20 30 40

densing, four-valve, Fleming engine, and has a normal capacity of 20 000 000 gal. per 24 hours, against a total suction and discharge head of 43 ft., and a maximum capacity of 25 000 000 gal. per 24 hours, against a total head of 45 ft.

*Generating Units.*—The electrical equipment consists of two 100-kw., 250-volt, direct-current, Crocker-Wheeler generators, each direct-connected to an 11 and 21-in. by 12-in. vertical, cross-compound, Shepherd engine. The switch-board is of marble, and has two generator panels and one feeder panel, with the usual station instruments and with integrating watt meters on the lighting and power circuits which run to the purification works.

*Flushing Pump.*—For flushing out the settling basins, mixing tanks, and lime saturators of the purification works, raw water is used, and is supplied by a 12 and 20-in. by 15 by 15-in. horizontal, Worthington, compound, direct-acting pump with outside center-packed plungers. The pump has a normal capacity of 1 500 gal per min. against a total head of 140 ft., a minimum capacity of 250 gal. per min., and a maximum capacity of 2 000 gal. per min. The suction of the pump is connected with the 48-in. discharge pipe from the low-lift pumps supplying raw water to the purification works. An additional suction, extending to the bottom of the main gullet, has also been provided for use in case the automatic sump pump should be out of service, or should the condition arise whereby a relatively large quantity of water would find its way into the main gullet, due either to an accident, or to an excess of ground-water, as previously mentioned.

*Wash-Water Pump.*—Filtered water for washing the filters in the purification works is supplied to the wash-water tank by a 9 and 14-in. by 15 by 15-in. horizontal, Worthington, compound, direct-acting pump, having a normal capacity of 1 300 gal. per min. against a total head of 60 ft., and a maximum capacity of 1 600 gal. per min. The pump is controlled automatically by the level of the water in the wash-water tank, starting when the level drops to Elevation 86.5 and stopping when the level reaches Elevation 87.0. The suction is taken from a main connected with the suction pipe of one of the vertical, triple-expansion pumping engines.

*Boiler Feed Pumps.*—The boilers are fed by two 12 and 7½-in. by 10-in. brass-fitted, Worthington pumps of the duplex, double-acting, outside-packed plunger type, each having a capacity of 150 gal. per

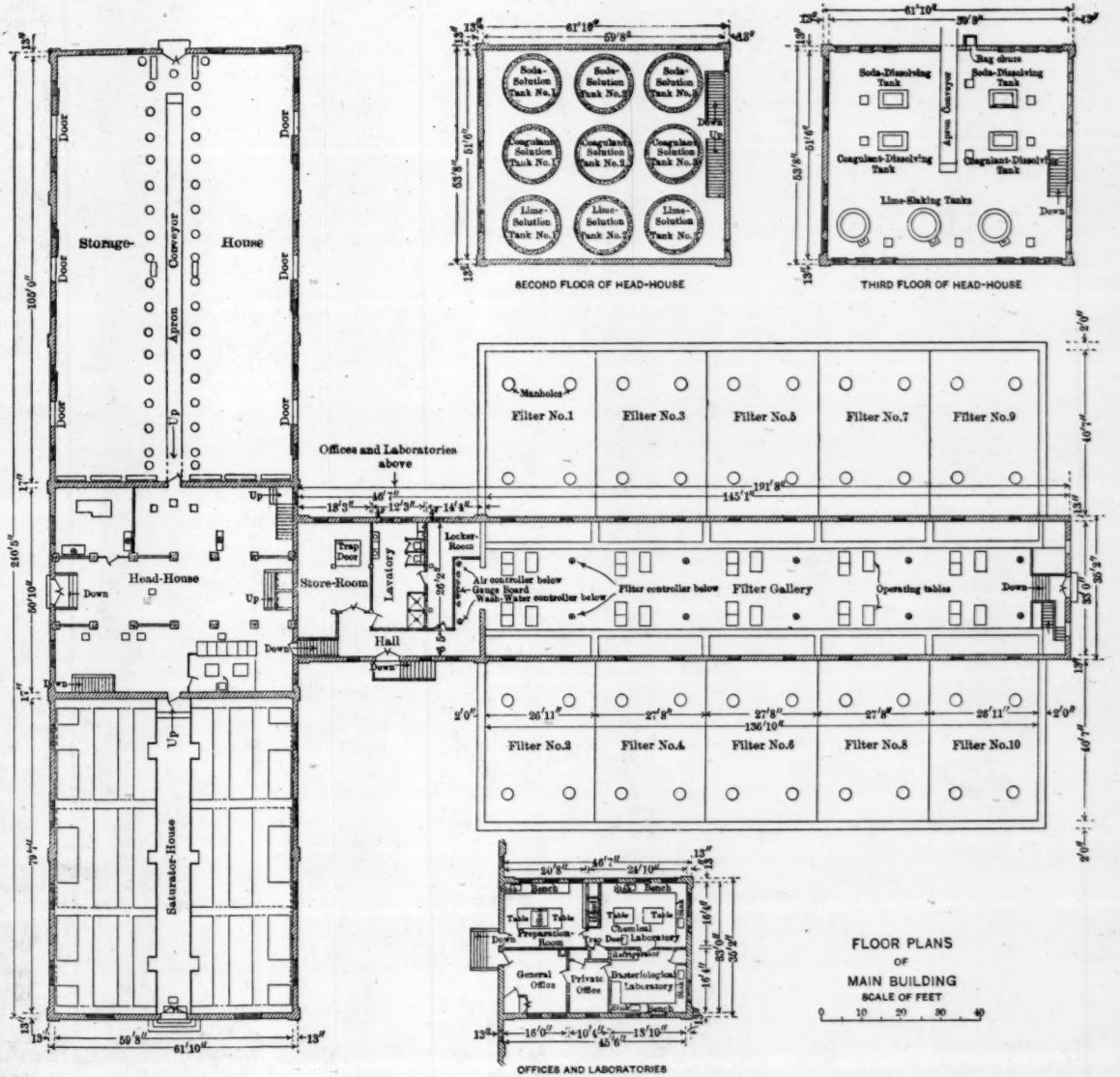
min., with water at 210° Fahr., against a steam pressure of 175 lb. per sq. in. Hot water is ordinarily supplied to the pumps from an open feed-water heater, but a separate cold-water supply is provided for use when the heater is out of service.

*Independent Surface Condenser.*—The exhaust steam from the low-lift pumping units, generating units, and flushing pump is piped to an independent Worthington surface condenser having 1 600 sq. ft. of cooling surface. The condensation is discharged by an 8 and 14-in. by 10-in. vertical, fly-wheel, suction-valveless, vacuum pump to the open feed-water heater. The circulating pump is a single-suction, horizontal, Worthington, volute pump, with 8-in. suction and 6-in. discharge nozzles, direct-connected to a vertical, single, 5 by 5-in. Blake engine. The circulating water is taken from a main connected with the 42-in. suction pipe of one of the vertical, triple-expansion pumping engines, and is returned to the suction pipe of the other pumping engine, the connections to both suction pipes being between the filtered-water suction well and the valves controlling the flow through the suction pipes.

*Open Feed-Water Heater.*—A Cochrane, open, feed-water heater, capable of raising the temperature of 50 000 lb. of water per hour from 100° to 210° Fahr., receives the condensation from the surface condensers of the vertical, triple-expansion pumping engines, from the independent surface condenser, and from the various steam separators and receivers, and also the exhaust steam from the wash-water pump, the independent circulating and vacuum pumps, and the boiler feed pumps. The feed-water heater serves as the hot well, and is raised from the floor of the engine-room basement so as to produce a head of about 4 ft. on the suction valves of the boiler feed pumps.

*Sump Pump.*—As the basement of the engine-room is too low to provide natural drainage at all times, a sump has been built, at the north end of the main gullet, which receives the water from the various drips and drains. On the bottom of the sump is placed a submerged 3-in., Worthington, vertical, volute pump having a capacity of 250 gal. per min. against a head of 20 ft. The pump is direct-connected to a 220-volt, enclosed, 5-h.p., Crocker-Wheeler motor, placed 2 ft. above the basement floor of the engine-room. The pump and motor operate automatically, starting when the level of the water reaches any desired point between Elevations 29.0 and 32.0, and stopping when the level

PLATE XII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



drops to Elevation 27.0. The water is discharged into a drain leading to the river.

*Boilers and Flue.*—The boiler-room contains four 300-h.p., Babcock and Wilcox, horizontal, water-tube boilers, carrying steam at 160 lb. pressure. Space has been left, and the foundations built, for two additional boilers. At present the boilers are fitted with shaking grates, and are hand-fired, but the construction is such that mechanical stokers can be added when desired. The ash-pits are arranged with hopper bottoms below the level of the boiler-room floor, and are provided with chutes through which the ashes are discharged into ash cars in the coal and ash tunnel. Each boiler is provided with a hot-water meter on the feed pipe, and an automatic stop check-valve on the steam nozzle, in addition to the regular gate-valve.

The flue, the maximum section of which is 5 ft. wide and 12 ft. high, is of brick masonry, 12 in. thick, and is supported on steel I-beams. The floor of the flue is arched, and in the roof the brick-work is carried on steel tees. The draft is controlled by a damper and automatic damper regulator.

*Steam Distribution.*—In the steam supply lines a modified unit system of piping has been followed. The steam header is divided by double valves into two sections, the northerly section being over one battery of boilers and the southerly section over the other battery. Ordinarily, the valves are open. From one boiler in a battery a direct line is run to one vertical, triple-expansion, pumping engine, a branch connecting with the header, and from the other boiler a direct line is run to each pair consisting of one low-lift pumping unit and one generating unit, a branch from this line also connecting with the header. The other section of the header is similarly connected with the other pumping engine and low-lift pumping and generating units. Separate lines, run from each section of the header, supply steam to the boiler feed pumps, the lines being cross-connected, with double valves, in the engine-room. Steam for the flushing, wash-water, and independent circulating and vacuum pumps is taken from the lines supplying the boiler feed pumps.

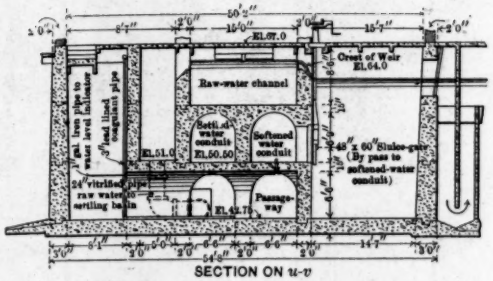
*Piping and Valves.*—All cold-water pipes 4 in. in diameter and greater are of cast iron; if less than 4 in. they are of wrought iron, galvanized. Steam pipes greater than 2 in. are of wrought iron with rolled-steel flanges. Steam and hot water pipes less than 2 in., and the

boiler feed pipes, are of brass. Exhaust pipes 6 in. and greater are of cast iron; if less than 6 in., they are of wrought iron. The drips from the exhaust separators are collected in two cylindrical tanks which, when full, automatically sound a high-water alarm. The tanks are then blown off to the sump at the end of the main gullet.

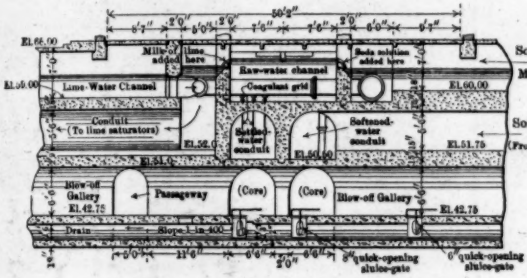
The gate-valves in the 30-in. discharge pipes of the low-lift pumps, and in the 42-in. suction and 36-in. discharge pipes of the pumping engines, are of the Coffin make, electrically-operated, but designed so that they may be opened or closed by hand if desired. No foot-valves or gate-valves have been placed on the suction pipes of the low-lift pumps, the valve in the discharge pipe being closed when a pump is not running. Each set of electrically-operated valves is controlled from a marble switch-board or panel fitted with controllers and indicators. The gate-valves on the steam lines and on water lines, other than those just mentioned, are of the Crane make, fitted with rising stems, those 2-in. and greater having outside screws and yokes. All valves except a few of the small ones are flanged.

*Water Meters.*—All water is metered. The raw water pumped to the purification works passes through a 48-in. Venturi meter, an indicator and chart recorder being placed in the head-house of the purification works, and a register and manometer in the pumping station. All the filtered water pumped by the pumping engines passes through a 48-in. Venturi meter, the register and manometer for this meter also being in the pumping station. For supplying filtered water for the pumping station and purification works, a line connecting with the force mains below the Venturi meter is run back into the pumping station, where several branches are taken off, with a meter in each, supplying, respectively, the boiler feed make-up, the hydraulic elevator, the plumbing and other fixtures in the building, the purification works, and the wash-water tank. The line last mentioned provides another means of supplying filtered water to the wash-water tank, and is used when the wash-water pump is not running, the flow being controlled automatically by a Golden-Anderson, altitude valve.

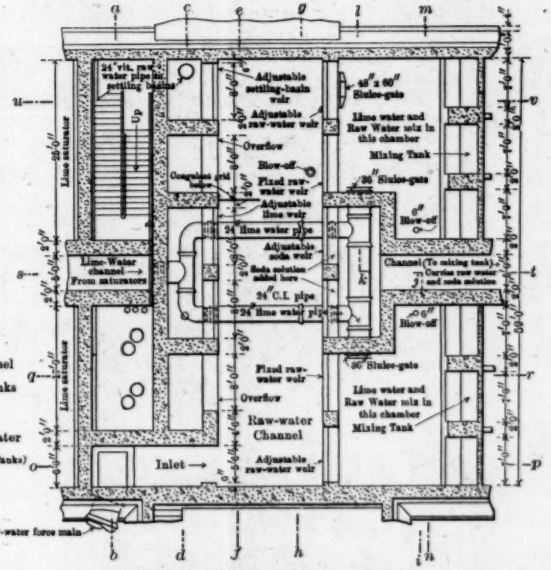
*Coal and Ash Handling Equipment.*—For handling coal and ashes, a Hunt industrial railway has been installed in the coal pocket, boiler-room, and coal and ash tunnel. Ordinarily, the coal is drawn from the coal pocket, through chutes and hand-operated outlet-valves, into charging cars in the tunnel. The cars are raised by a direct-lift,



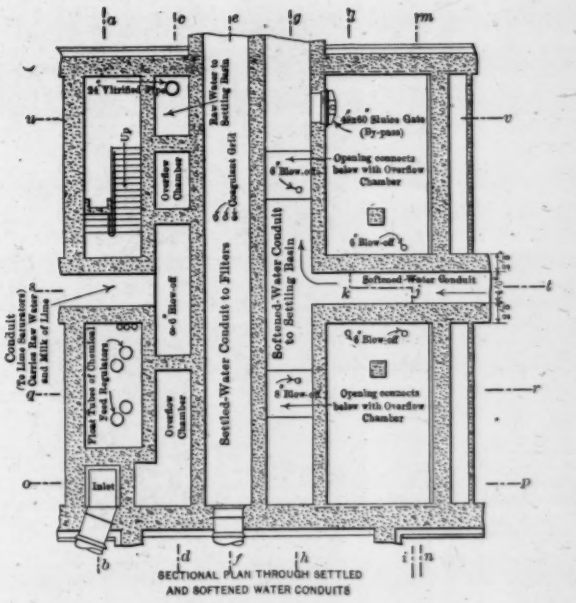

SECTION ON *u-v*



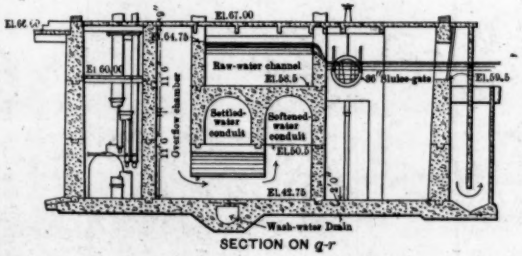

SECTION ON *s-t*



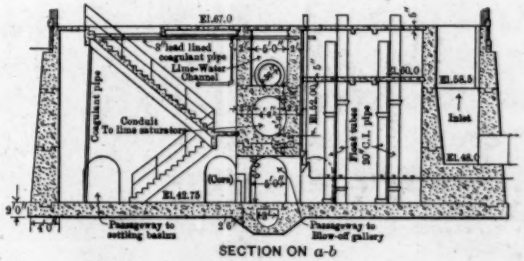

SECTIONAL PLAN BELOW FIRST FLOOR



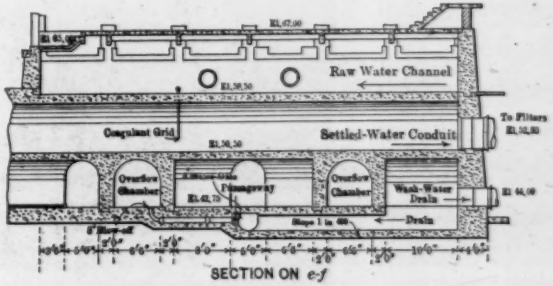

SECTIONAL PLAN THROUGH SETTLED AND SOFTENED WATER CONDUITS



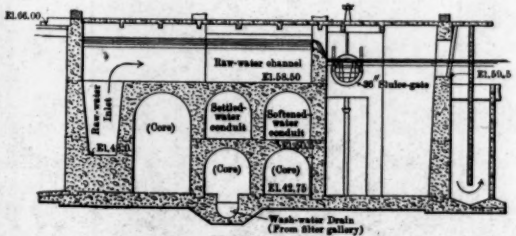

SECTION ON *q-r*



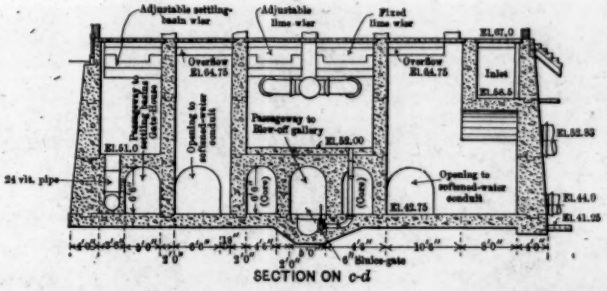

SECTION ON *a-b*



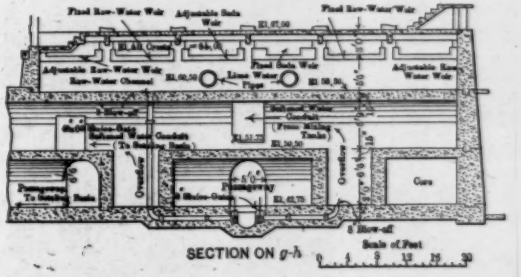

SECTION ON *e-f*




SECTION ON *o-p*

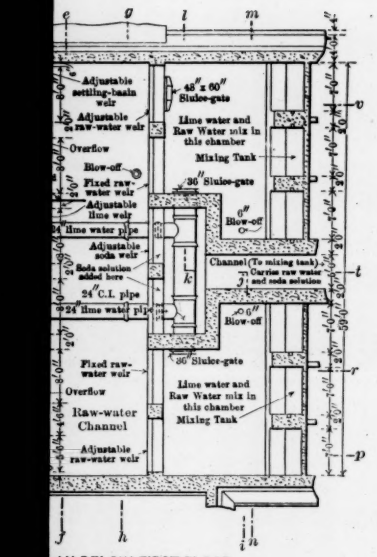



SECTION ON *c-d*

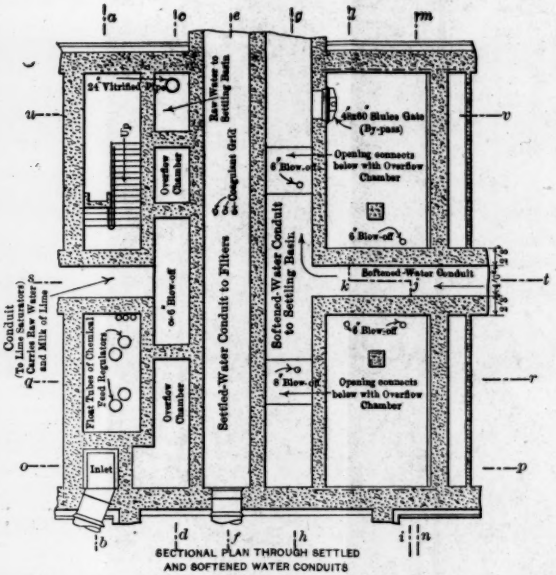



SECTION ON *g-h*

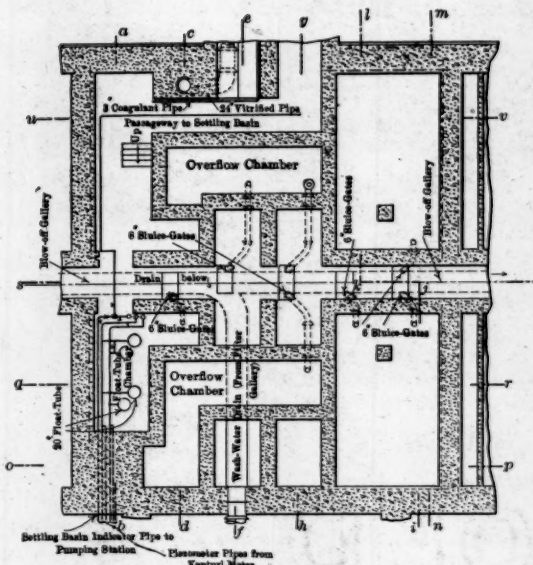
PLATE XIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



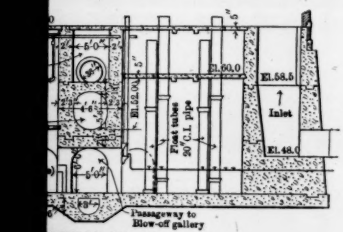

PLAN BELOW FIRST FLOOR



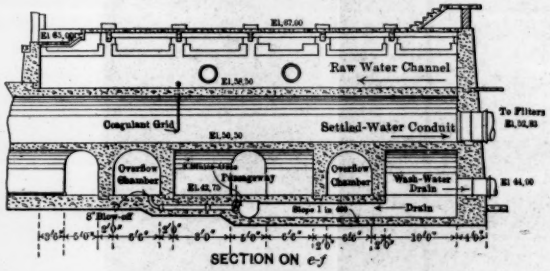

SECTIONAL PLAN THROUGH SETTLED AND SOFTENED WATER CONDUITS



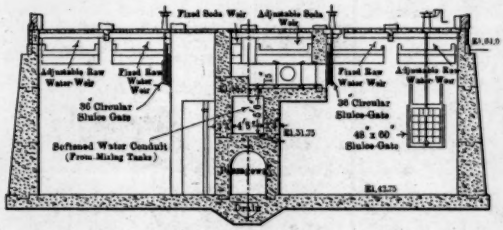

SECTIONAL PLAN ABOVE BOTTOM FLOOR



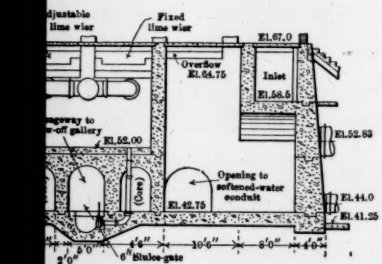

SECTION ON a-b



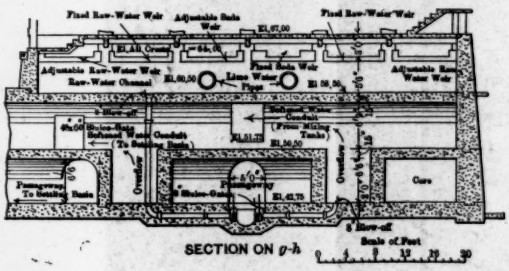

SECTION ON e-f



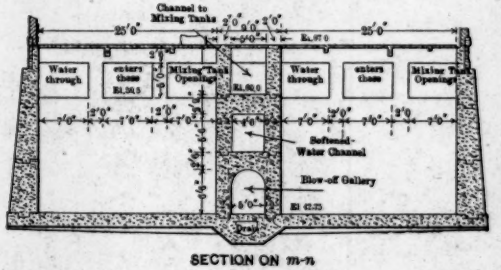

SECTION ON i-j-k-l




SECTION ON c-d




SECTION ON g-h




SECTION ON m-n

hydraulic elevator to the boiler-room floor, and then pass over a boiler-room track scale. At times, coal is also loaded by hand and run directly from the coal pocket into the boiler-room. The ashes are raked out into tip cars in the tunnel which are then taken out through the boiler-room and run over a track to the ash-dump where, for the present, they will be used in filling up an old gravel pit in front of the pumping station. The boiler-room, coal pocket, and tunnel have been designed so that an elevated coal bunker and conveyors can be added if desired, but, as the boilers at present have a total capacity of only 1 200 h.p., it was considered that the expense of this additional installation was hardly warranted.

*Crane.*—The engine-room is provided with a 20-ton, Case, electric crane having a span of 68 ft. 10 in. and a travel the full length of the room. The crane is fitted with 220-volt, slow-speed motors. With full load, the hoist has a speed of 12 ft., the trolley 100 ft., and the bridge 200 ft. per min., and a total lift of 57 ft.

## The Water Purification Works.

In the description of the water purification works, which follows, it should be noted that the problem of purifying the water was not simply one of filtration, but of softening and filtration combined, and has required, therefore, not only mechanical filtration works, but softening works in addition. It should also be borne in mind that the Scioto River water is hard and at times highly turbid, and, in periods of flood, changes its character very rapidly from hour to hour, one especially troublesome feature being a very rapid increase in turbidity with a correspondingly rapid decrease in hardness. The works have been designed to meet these conditions, and it is on this account that various features of the work are somewhat different from ordinary standard practice.

### Head-House.

The head-house, where some of the most important phases in the operation of the water purification works are controlled, is located practically in the center of the purification works. The raw water pumped from the river is first received in the substructure of this house, which is essentially a large gate-chamber.

The superstructure is a three-story building, on the first floor of which are located the devices for controlling the flow of water through

the substructure, the regulators for controlling the rate of application of the chemical solutions, the air compressor, and the motors for driving the stirring machinery of the lime saturators. Access is also had from this floor to the saturator-house, storage-house, offices and laboratories, and filter gallery, and also to the gate-house by means of an underground passageway. The second floor is given up entirely to nine large tanks in which the chemical solutions are stored, and the dissolving and slaking tanks are on the third floor. Sections through the head-house are shown on Fig. 9.

*Substructure.*—The substructure of the head-house, which is of more or less complicated design, and is built of concrete reinforced at points, is shown in detail on Plate XIII.

The operation will be best understood by following the flow of the water. The raw water is first admitted to the raw-water channel, along each side of which are located the so-called head-house weirs. One portion of raw water passes over the lime weir, where milk of lime is added to it, and then flows to the lime saturators where it is converted into lime-water. Returning from the saturators the lime-water passes through two lime-water pipes into the two large raw-water chambers.

A second portion of raw water passes over the raw-water weirs into the two raw-water chambers just mentioned, where it mixes with the lime-water, the two then flowing into the mixing tanks.

A third portion of raw water passes over the soda weir, where a solution of soda ash is added, after which the raw water and soda solution flows out through the soda channel and thence into the mixing tanks at the points shown on Plate XVI, where it mixes with the raw water already treated with lime-water.

Returning from the mixing tanks, where the softening reactions largely take place, the water passes in the softened-water conduit back through the head-house and out to the settling basins, from which it returns through the head-house again, this time in the settled-water conduit, and passes to the filter gallery.

In addition to the weirs just mentioned, a fourth weir, known as the settling-basin weir, has been provided, over which, when desired, raw water from the raw-water channel can be discharged into a chamber and thence through a 24-in. pipe out through the main dividing wall of the settling basins, the object being to admit a small quantity of raw water to the softened water prior to filtration, in order to eliminate traces of caustic alkalinity.

Provision has also been made in the substructure of the head-house to by-pass the mixing tanks, as will be seen by referring to Plate XIII, raw water being admitted directly from one of the raw-water chambers through a 4 by 5-ft. sluice-gate into the softened-water conduit leading

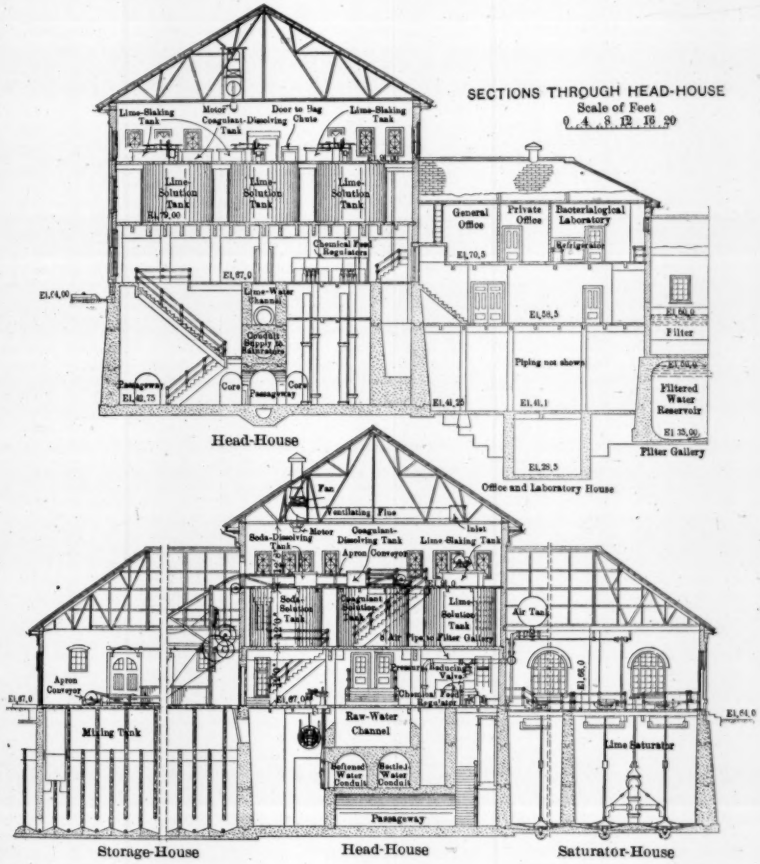



FIG. 9.

to the settling basins. Further, by a combination of stop-plank openings in the east end of the main dividing wall of the settling basins, as shown on Plate XVII, it is possible to by-pass the settling basins, the water flowing from the softened-water conduit into the settled-water

conduit and thence to the filter gallery. In the latter case, coagulant would be added to the raw water through a grid placed in the settled-water conduit, as shown on Plate XIII. It is probable that, if both mixing tanks were shut off, no attempt would be made to soften the water during such time as the tanks were out of service.

To prevent flooding the first floor of the head-house, if by accident the openings through which water would normally flow into the lime saturators and mixing tanks should be closed, two overflows have been placed on the south side of the raw-water channel over which the water would flow into two chambers connecting with the softened-water conduit and thence to the settling basins where it would be cared for by another set of overflows connecting with the drain running to the river. If, however, the settling basins were shut off from the head-house, the overflows last mentioned would be of no service, and, to prevent flooding, it would require that the filters be operated at such a rate as to care for all the raw water pumped into the head-house. This latter condition is seldom likely to arise, and then only for short periods of time, and, with a little added care on the part of the filter attendant, no trouble should be experienced.

The lower part of the substructure is reached from the first floor by a stairway, at the foot of which passageways lead to the blow-off galleries of the lime saturators and mixing tanks and to the spiral staircase in the main dividing wall of the settling basins.

*Head-House Weirs.*—With the exception of the settling-basin weir, the head-house weirs are adjustable, by movable flash-boards, from a fixed minimum to the maximum length. The settling-basin weir is adjustable for its full length. Each flash-board consists of a plate held on the outer end of an arm pivoted on a horizontal shaft, the arm, and thereby the plate, being raised or lowered by a rod extending up through the floor above. The total length of the head-house weirs is 56 ft. 10 in., but, of this length, it was expected that only 45 ft. 10 in., equal to 100%, would be in use at any one time. Each flash-board, with the exception of two which have a width of 2¾ in., has a width of 5½ in., corresponding to 1% of the 45 ft. 10 in. The dimensions of the weirs as built are given in Table 7.

The rods operating the flash-board arms are held in guides, each guide being provided with a locking device, so that, after the weirs are properly adjusted for any condition of the raw water, the adjustment

PLATE XIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

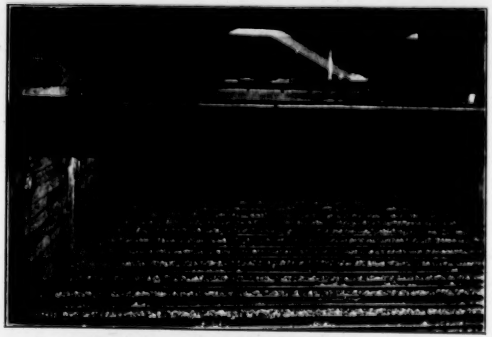


FIG. 1.—INTERIOR OF FILTER, SHOWING LATERAL AIR PIPES AND CONCRETE RIDGES BETWEEN STRAINER SLABS.

FIG. 2.—INTERIOR OF FILTER, SHOWING STRAINER SLABS SET IN PLACE.

FIG. 3.—INTERIOR OF FILTERED-WATER RESERVOIR: SIDE-WALL CONSTRUCTION.

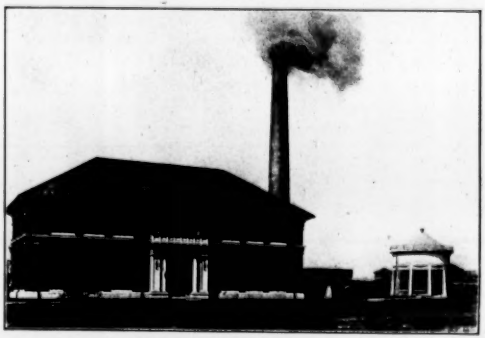


FIG. 4.—SCIOTO RIVER PUMPING STATION.

cannot be changed without the knowledge of the person in responsible charge of the shift on duty. With a flow of 30 000 000 gal. per 24 hours, the head on the weirs would be about 0.45 ft., and about 0.55 ft. with a flow of 40 000 000 gal. per 24 hours.

TABLE 7.—DIMENSIONS OF HEAD-HOUSE WEIRS.

Net length in use, 45 ft. 10 in. = 100 per cent. 1% = 5½ in.

| Weir. | Fixed Portion. | | Adjustable Portion. | | Total. | |
|---|---|---|---|---|---|---|
| | Percentage of 45 ft. 10 in. | Length. | Number of flash-boards. | Length. | Percentage of 45 ft. 10 in. | Length. |
| Lime | 11 | 5 ft. 0½ in. | 13 | 5 ft. 11½ in. | 24 | 11 ft. 0 in. |
| Raw water | 50 | 22 ft. 11 in. | 15 | 6 ft. 10½ in. | 65 | 29 ft. 9½ in. |
| Soda | 15 | 6 ft. 10½ in. | 10 | 4 ft. 7 in. | 25 | 11 ft. 5½ in. |
| Settling basin | 0 | 0 | 10 | 4 ft. 7 in. | 10 | 4 ft. 7 in. |
| Total | 76 | 34 ft. 10 in. | 48 | 22 ft. 0 in. | 124 | 56 ft. 10 in. |

When the works were designed it was thought that sufficient adjustment in the length of the several weirs had been provided to meet the varying conditions which were likely to arise, but it has been found, as a result of the operation of the works during the last year, that greater adjustment is necessary, and it is proposed to modify the construction accordingly.

*Dissolving Tanks.*—For dissolving the soda ash and coagulant, four tanks have been provided, two for each chemical. The tanks are of concrete, rectangular in plan, 5 ft. long, 3 ft. wide, and 2 ft. 8 in. deep. In the coagulant tanks the material to be dissolved is placed on a screen raised 3 in. above the floor of the tank, covering the whole width, and extending nearly to each end of the tank. At the inlet end a baffle extends from the top of the tank to the bottom of the screen, and at the outlet end another baffle extends from the bottom of the tank to within 8 in. of the top, above which is placed a screen. Water, which can be heated by steam if desired, is admitted back of the inlet baffle, passes down and under the horizontal screen, then up through the material to be dissolved and off through the screen over the outlet baffle. The outlet from the tank is also protected by a removable cylindrical screen, 3½ in. in diameter and 2 ft. 2 in. long. The baffles and screens

are of copper. In the soda tanks the arrangements are in general similar, except that the false bottom, originally provided, has been removed and replaced with an ejector-type heater to produce suitable circulation of the liquid in the tank.

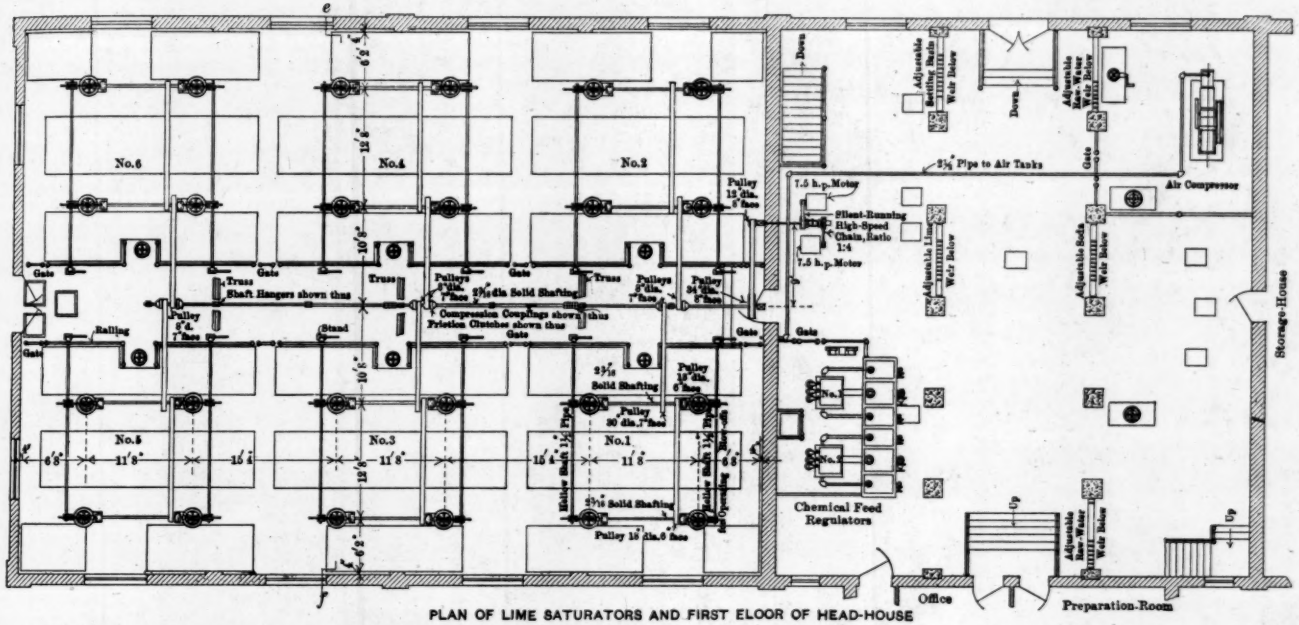
*Soda and Coagulant-Solution Tanks.*—The soda and coagulant solutions are stored temporarily in six large cylindrical tanks, three for each solution. The tanks are of reinforced concrete, 12 ft. 6 in. in diameter and 11 ft. 5 in. deep. The piping from the dissolving tanks is arranged so that either or both of the dissolving tanks for one of the chemicals can discharge into any or all of the three solution tanks for the same chemical. Separate water connections are made for each solution tank, so that solutions of the required strength can be made up. Compressed air is used for agitation, to prevent stratification of the solutions.

*Lime-Slaking and Solution Tanks.*—The three lime-slaking tanks are of reinforced concrete, and are 6 ft. in diameter and 2 ft. 8 in. deep. The lime and water are stirred, during the process of slaking, by vertical rakes carried on horizontal arms and driven through gearing and a silent-running high-speed chain by a 220-volt, 1½-h.p. Crocker-Wheeler, variable-speed motor. After the lime is slaked, the tank is discharged into a so-called lime-solution tank below, where, by the addition of more water, milk of lime of the required strength is made up. There are three reinforced concrete lime-solution tanks, each 12 ft. 6 in. in diameter and 11 ft. 5 in. deep. The milk of lime is agitated by a vertical shaft and horizontal paddles driven from the motor which operates the stirring rakes in the slaking tank.

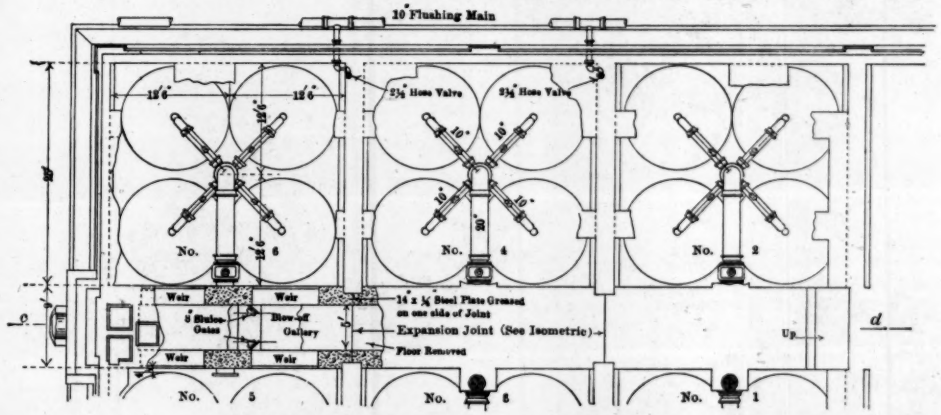
*Chemical Feed Regulators.*—The chemical solutions are fed automatically in proportion to the quantity of raw water pumped into the head-house, this being accomplished by a specially designed chemical feed regulator, provided in duplicate, and operated by the difference in head on the up-stream end and throat of the 48-in. Venturi meter located in the raw-water force main just outside of the head-house.

*Air Equipment.*—Air, for use in washing the filters, is furnished by a Bury air compressor, placed on the first floor of the head-house. It has a rated capacity of 100 cu. ft. of free air per min. compressed to a gauge pressure of 60 lb. per sq. in., and is driven by a 15-h.p., 220-volt, Crocker-Wheeler motor. The compressed air, prior to use in washing, is stored in three tanks supported in the roof trusses of the saturator-

PLATE XV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

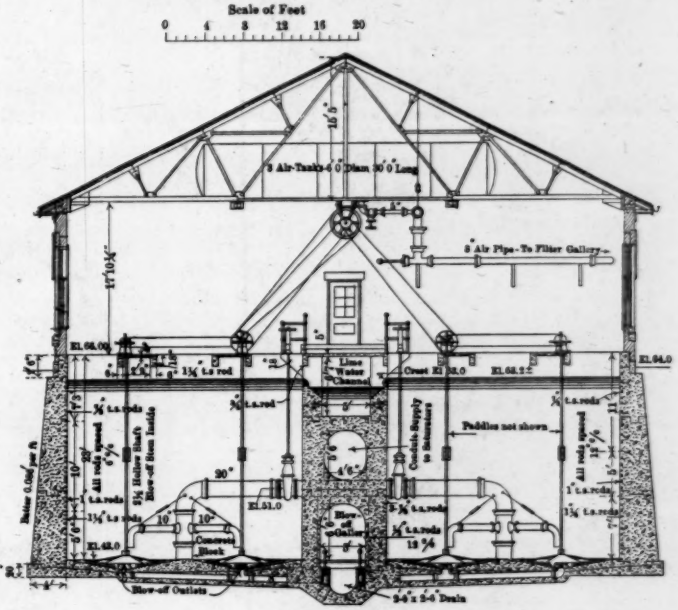



PLAN OF LIME SATURATORS AND FIRST FLOOR OF HEAD-HOUSE

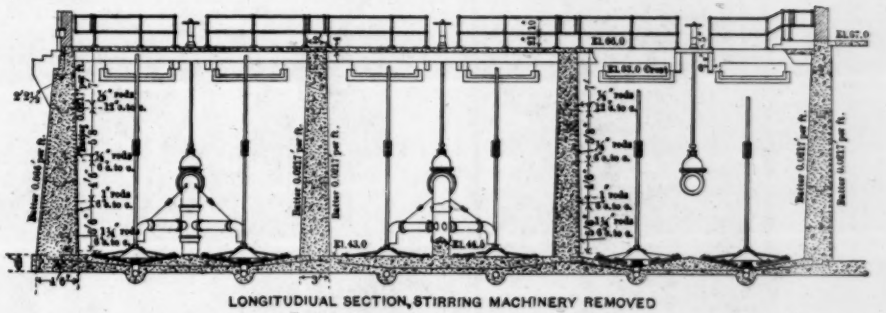



PLAN OF PART OF LIME SATURATORS. (STIRRING MACHINERY NOT SHOWN)

## LIME SATURATORS




CROSS-SECTION




LONGITUDIUAL SECTION, STIRRING MACHINERY REMOVED

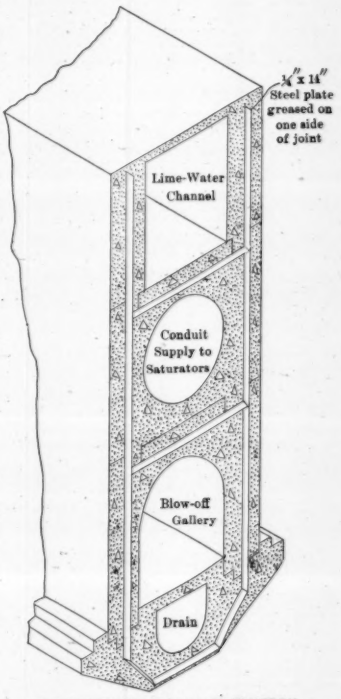
house, each tank being 6 ft. in diameter and 30 ft. long, and built of ¼-in. riveted steel plate. An 8-in. air pipe runs from the air tanks to the filter gallery, and, in this line, as it passes through the head-house, is placed an oil separator and a Foster pressure-reducing valve, which maintains a practically constant pressure of from 2 to 4 lb. per sq. in. on the outlet side as may be desired. The air tanks are of sufficient capacity to permit one filter being washed about every 1¾ hours, for about 3 min., at a maximum rate of 3 cu. ft. per sq. ft. per min.

## Saturator-House.

The six lime saturators are in a wing of the main buildings just south of the head-house, and are shown in detail on Plate XV. Raw water, to which a solution or suspension of milk of lime has been added in the head-house, is brought out through the middle conduit in the main dividing wall, and passes into each saturator through a 20-in. cast-iron pipe, branching into four 10-in. pipes. Rising slowly through the saturators, lime-water is produced and flows over the weirs into the lime-water channel and thence back to the head-house and into the two large raw-water chambers, where it mixes with the bulk of the raw water which is to be softened.

The saturators were designed for a maximum upward velocity of about 10 ft. per hour and to produce a total of about 6 750 000 gal. of lime-water per 24 hours.

*Construction of Tanks.*—The saturators are of concrete, heavily reinforced, each tank being 25 ft. square and 20 ft. deep. The bottom of each saturator is in




ISOMETRIC SECTIONAL ELEVATION SHOWING EXPANSION JOINT.

Fig. 10.

the form of four inverted cones, in the center of each of which is a 6-in. outlet for blowing off sludge. These outlets connect with pipes running to the drain below the floor of the blow-off gallery, the end of each blow-off pipe being provided with an 8-in., quick-opening, circular sluice-gate with lever handle. Each 6-in. outlet is fitted with a loose disk or valve, operated from the top of the main dividing wall, so that the four inverted cones may be blown off separately.

*Stirring Machinery.*—To prevent the deposition of the lime, and to insure thorough mixing of the lime solution with the water, the liquid in the saturator is agitated slightly. The agitators, of which there are four to each saturator, consist, at the bottom, of conical hoods, 4 ft. in diameter, of ¼-in. steel plate, and carrying two arms or paddles. The paddles are set up about 2 in. from the surface of the conical bottom, and revolve slowly at a speed varying from 3 to 4½ rev. per min., as may be desired. Paddles are also provided on the vertical shafts.

The agitators are driven by vertical hollow shafts of 2-in. wrought-iron pipe, which in turn derive their motion through bevel gearing and countershafts. A line shaft, hung from the lower chord of the roof trusses, is belted to the countershafts and to a jack-shaft. The agitators for each saturator are controlled by friction clutches on the line shaft. The jack-shaft is driven through a silent-running, high-speed, Morse chain by a 7½-h.p., variable-speed, 220-volt, Crocker-Wheeler motor. The motors for driving the machinery are in duplicate, and are located in the head-house.

## Storage-House and Mixing Tanks.

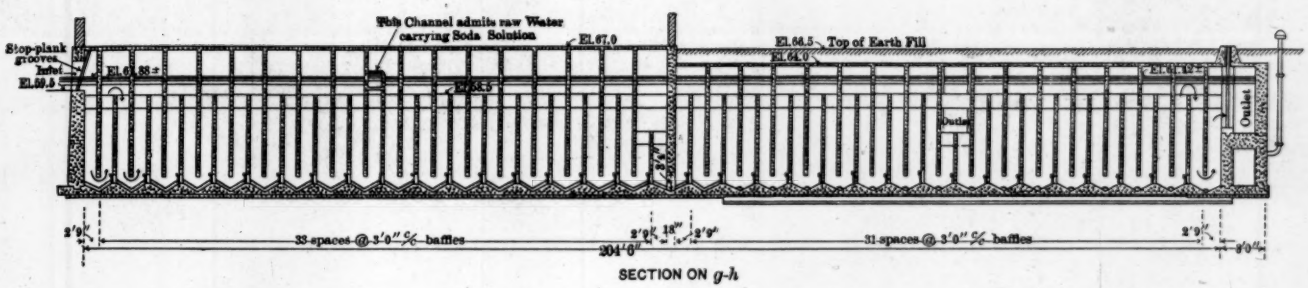
The storage-house and mixing tanks, the details of the latter being shown on Plate XVI, are in a wing of the main building just north of the head-house, the southerly portion of the mixing tanks being directly below the storage-house. There is a railroad spur on each side of the storage-house, the doors being spaced so that six cars may be set at one time for unloading.

*Storage-House.*—The storage-house consists of one large room, 59 ft. 8 in. wide and 105 ft. long, and is used for the storage of the chemicals used in the softening and purification processes. The floor of the storage-house, which serves also as the roof for that portion of the mixing tanks situated below, is designed for a live load of 500 lb. per

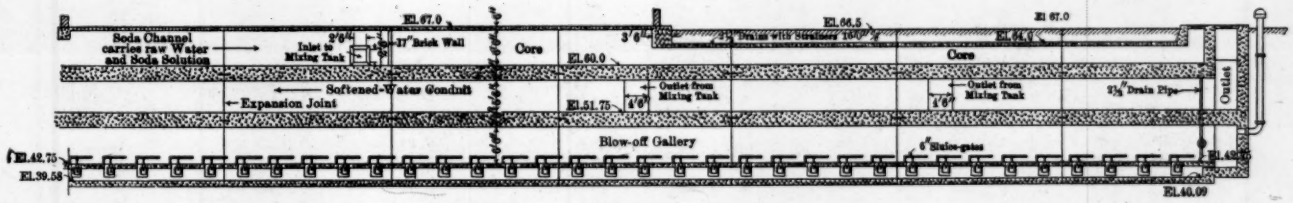
PLATE XVI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

# MIXING TANKS

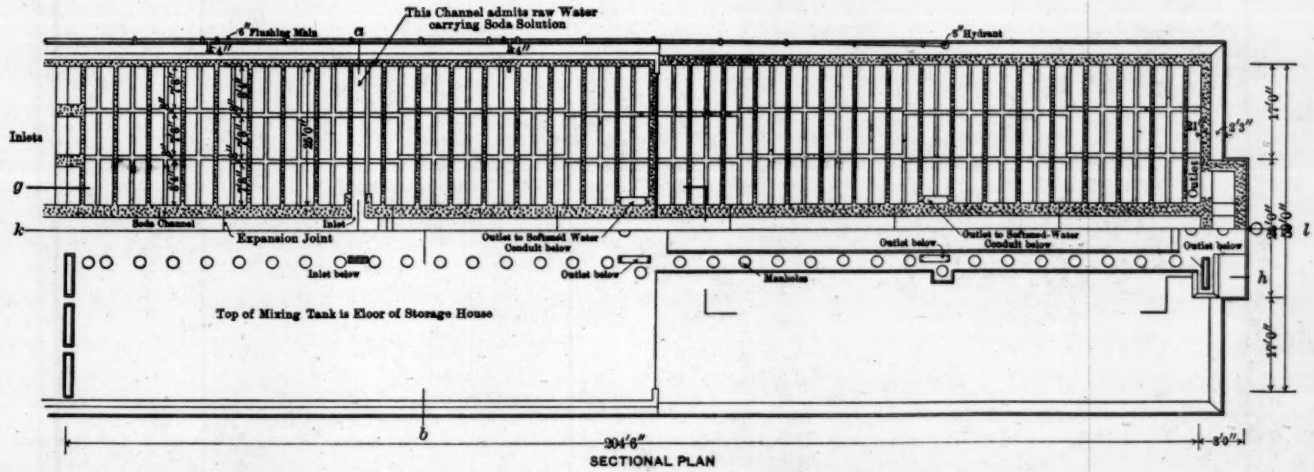
Scale of Feet
0 10 20 30 40



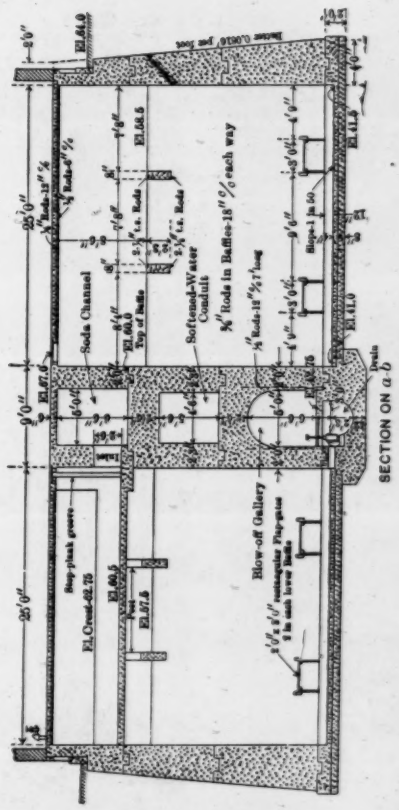

SECTION ON *g-h*




SECTION ON *k-l*



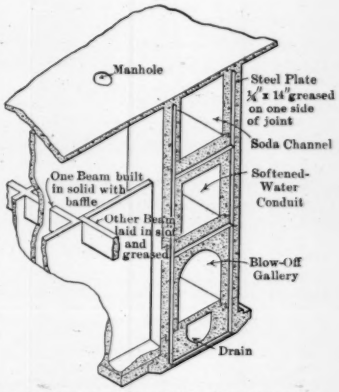

SECTIONAL PLAN




SECTION ON *a b*

sq. ft., and, on this basis, allowing space for the unloading and handling of the chemicals, the house has a maximum storage capacity of 900 tons, or about 20 carload lots.

The chemicals are handled in bags, each containing a net weight of 100 lb. From the floor of the storage-house the bags are transported by a Jeffrey apron conveyor to the third floor of the head-house, where the solutions are made up. The conveyor, which is in the center of the storage-house and extends nearly its full length, is driven by an 18-h.p., Crocker-Wheeler enclosed motor, and has a maximum carrying capacity of 12 bags per min. when running at a speed of 50 ft. per min.




ISOMETRIC SHOWING EXPANSION JOINT

FIG. 11.

*Mixing Tanks.*—The two mixing tanks, in which the softening reactions largely take place, are of peculiar construction, as they are highly baffled, the arrangement of the baffles being such as to tend to prevent sedimentation and keep the solids in suspension rather than to assist sedimentation. The operation of the tanks is as follows:

Raw water, to which lime-water has been added in the two large raw-water chambers in the head-house, enters the tanks at the surface at the southerly end. Passing vertically downward, it is deflected under the first baffle, then rises vertically, passing over the second baffle, then downward again, and so on. Another portion of raw water, to which the soda solution has been added in the head-house, flows out through the channel in the upper part of the dividing wall, and is then deflected laterally into two small channels over the down-stream edges of which it falls into the raw water to which the lime-water has already been added. From this point on, the raw water, which has now been treated with both lime and soda ash, flows through the tanks to the outlets, the mixture of the raw water with the lime-water and soda solution being ensured by the high degree of baffling.

Under normal conditions, when treating 30 000 000 gal. per 24 hours, a period of about 1 hour will be required for the water to pass through the mixing tanks. Provision has also been made so that the water may be drawn off, if desired, when it has passed either one-half or three-quarters of the way through the tanks. When treating 30 000 000 gal. per 24 hours the mean velocity through the tanks is about 0.37 ft. per sec. and about 0.5 ft. per sec. when treating 40 000 000 gal. per 24 hours.

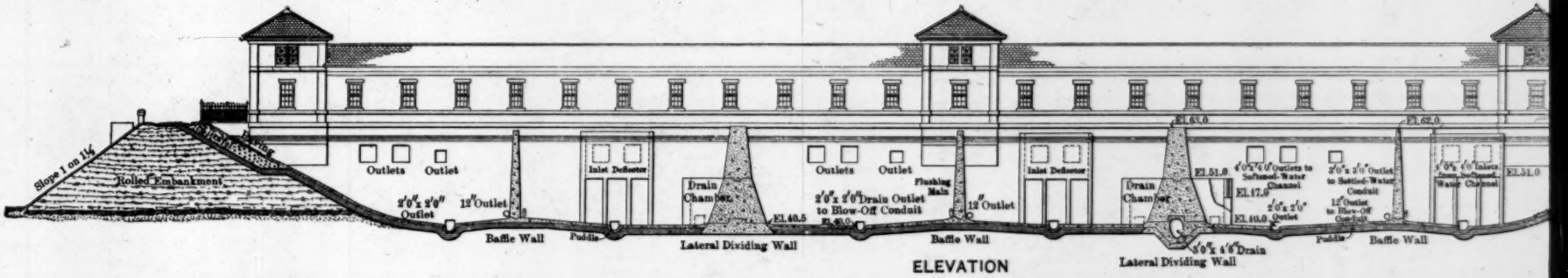
As designed, the tanks were intended to be operated in parallel only, but it has been found desirable at times to operate them in series, that is, to pass the water up through one tank and back through the other. This can be accomplished by the use of temporary bulkheads, but changes in the construction are contemplated so that this method of operation may be easily permitted when desired.

The tanks, which are constructed throughout of concrete, reinforced where necessary, are each 204 ft. 6 in. long and 25 ft. wide, and have a water depth of a little more than 20 ft., depending on the quantity of water passing through. The baffles are 6 in. thick, and are 3 ft. from center to center, the 68 chambers or pockets formed by the lower baffles being drained by 6-in., quick-opening sluice-gates which discharge into the drain in the bottom of the main dividing wall.

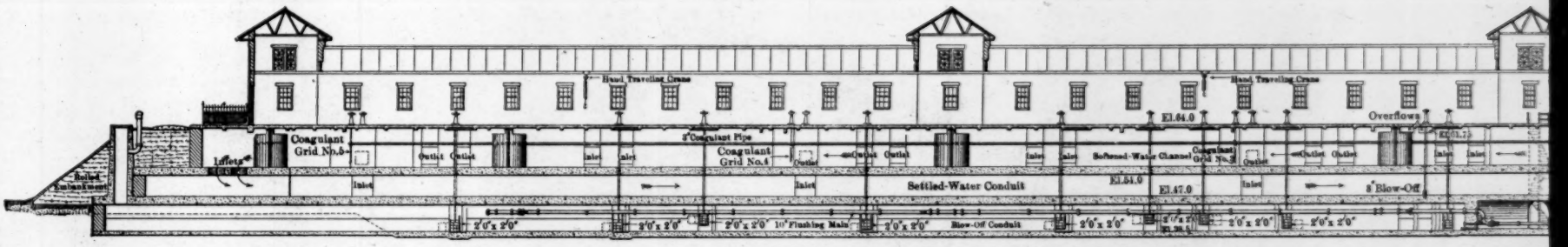
As the baffles were not designed to withstand water pressure on one side only, each lower baffle is fitted with two 2 by 3-ft. rectangular flap-gates, hung on bronze-mounted hinges and swinging in openings through these baffles, the gates being heavy enough to keep the opening closed when water is flowing through the tanks under the ordinary conditions of service, but swinging open under a slight difference of head on the two sides of the baffle caused by the opening of the 6-in. blow-off gates.

The dividing wall is of heavy cored construction, the upper passage or soda channel supplying raw water and soda solution to the tanks, as previously mentioned. The middle passage or softened-water conduit carries softened water from the outlets of the tanks back to the headhouse and to the settling basins. The lower passage or blow-off gallery provides access to the blow-off gates.

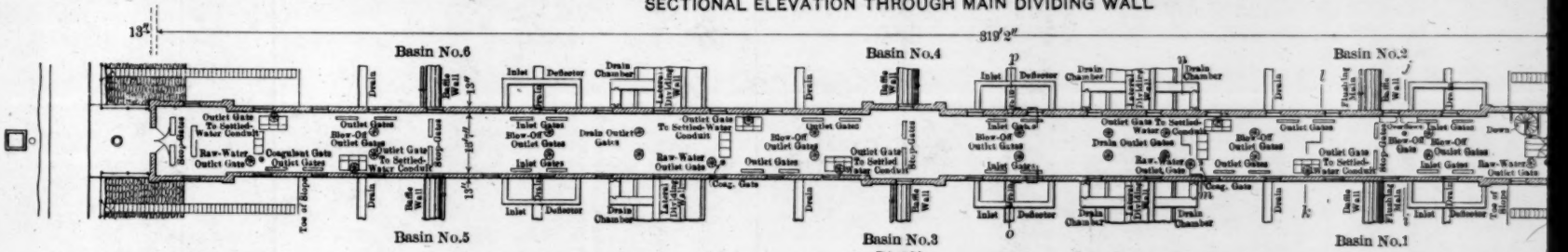
In order to keep the floor of the storage-house free of operating stands, and also to provide large openings, stop-planks, instead of sluice-gates, are used for controlling the flow of water at the inlets and outlets of the tanks.



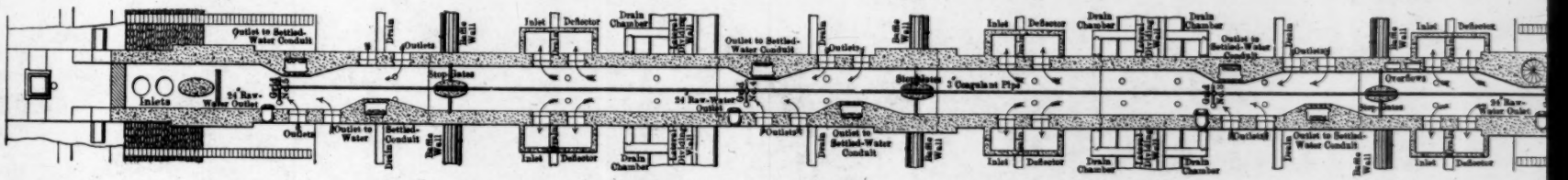

ELEVATION




SECTIONAL ELEVATION THROUGH MAIN DIVIDING WALL



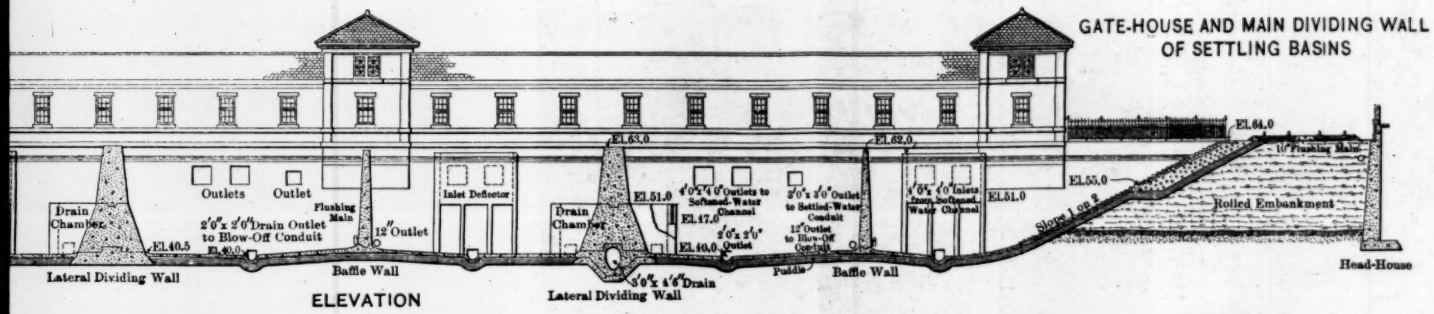

PLAN




SECTIONAL PLAN THROUGH SOFTENED-WATER CHANNEL

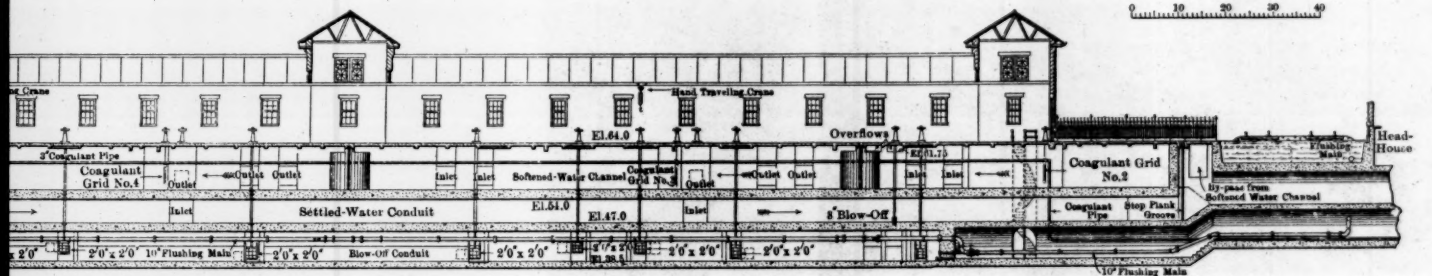
PLATE XVII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

## GATE-HOUSE AND MAIN DIVIDING WALL OF SETTLING BASINS

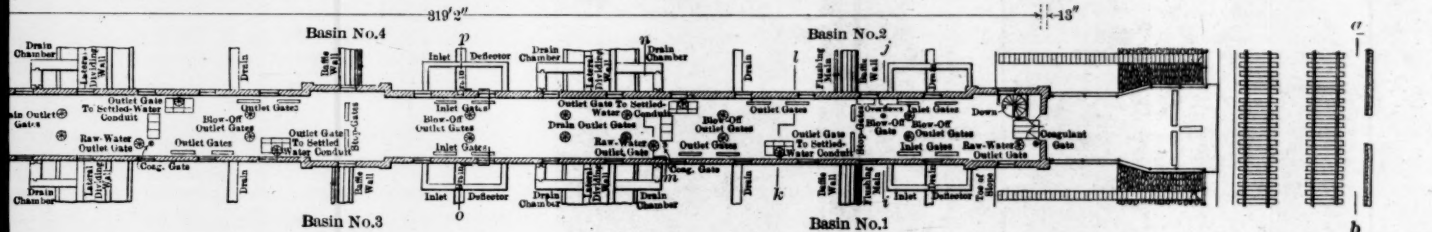



ELEVATION

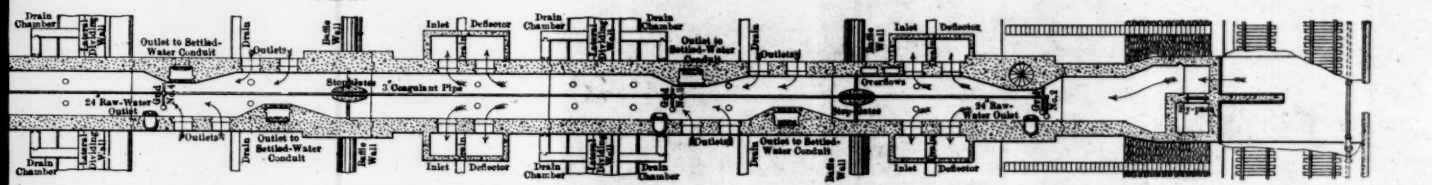
SCALE OF FEET
0 10 20 30 40



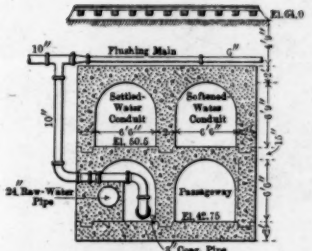

SECTIONAL ELEVATION THROUGH MAIN DIVIDING WALL



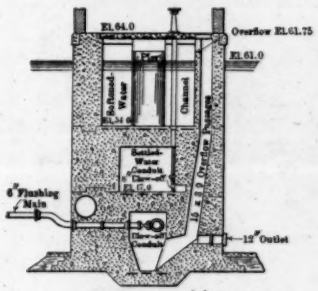

PLAN



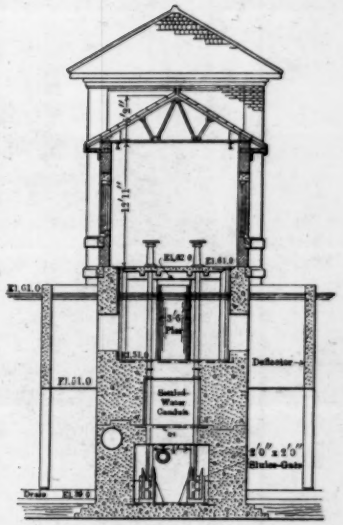

SECTIONAL PLAN THROUGH SOFTENED-WATER CHANNEL



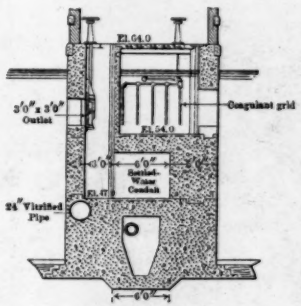

SECTION ON *a-b*



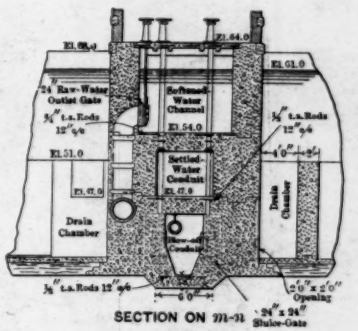

SECTION ON *i-j*




SECTION ON *o-p*




SECTION ON *k-l*




SECTION ON *m-n*

## Settling Basins.

The general plan of the six settling basins is shown on Plate IX, and Plate XVII shows the details of the embankments, walls, and gate-house. The six basins have a total capacity of approximately 15 000 000 gal., equivalent to 12 hours' subsidence when the purification works are running at their normal capacity. The water varies from 19 to 21 ft. in depth, the average being about 20 ft. The basins are operated on the continuous plan, that is, water is admitted continuously at one end and drawn off at the other. The normal water line is at Elevation 61.0, or 1 ft. above the normal water line on the filters. Should pumping cease, it would be possible to draw the basins down to about Elevation 58.0 before it would become necessary to shut down the filters, due to lack of water. The volume thus drawn would be about 2 700 000 gal., a quantity sufficient to supply the filters for a little more than 2 hours.

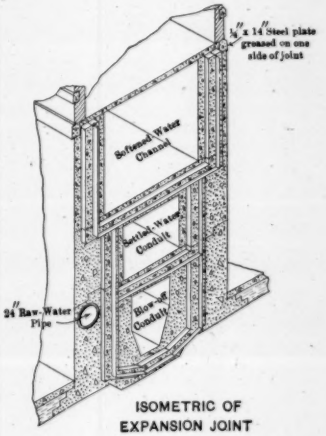



FIG. 12.

*Embankments and Floors.*—The embankments are composed of a mixture of gravel and loamy clay, in 6-in. layers, and well rolled. For water-tightness, dependence is placed on a lining of clay puddle, 18 in. thick on the bottom and lower part of the slope, and 12 in. thick on the upper part. The puddle, which was mixed rather wet and in the proportion of 1 volume of clay to 2 volumes of gravel, was placed in 6-in. layers and rolled with a grooved roller until hard. On the bottom and lower part of the slope the puddle is protected with a 6-in. concrete floor, and on the upper part of the slope with limestone paving, 10 in. thick, bedded on 2 ft. of screened gravel.

*Lateral Dividing and Baffle Walls.*—The lateral dividing and baffle walls are of concrete. The lateral dividing walls have a gravity section, and the baffle walls are stable against wind pressure when the basins are empty, but neither of the walls was designed to resist ice pressure. In the foundation under the dividing wall separating Basins Nos. 1 and 3, a 3 ft. by 4 ft. 6-in. drain has been built, connecting the

blow-off conduit in the main dividing wall with the drain running to the diverting chamber and to the river.

*Main Dividing Wall.*—The main dividing wall is also of concrete, and its rather complex design is illustrated on Plate XVII. The wall serves, not only as a dividing wall, but also to control the flow of water to the several basins and the return to the filters. The operation of the basins may be best followed by referring to Plates IX and XVII.

Softened water, on its return from the mixing tanks, passes through the head-house and is admitted to the softened-water channel at the east end of the main dividing wall. From this channel the water flows out through openings into Basins Nos. 1 and 2, passes under deflectors in order to interrupt surface currents, around the baffle walls, and back through other openings into the channel. The water then follows a similar course through the other basins until it reaches the west end of the channel, where it passes down through openings into the settled-water conduit and thence back through the head-house to the filter gallery. The course of the water is controlled by wooden gates, held in grooves and operated from the floor above.

It is also possible to operate the basins in a different way, namely, to admit water to all of them at once, instead of to each set of two basins in series, as just described, this being accomplished by raising all the stop-gates in the softened-water channel except those at the extreme west end, and by closing all the outlets from the basins to the channel. Settled water would then be drawn off from each basin through an opening connecting with the settled-water conduit.

A 3-in., lead-lined, iron pipe extends practically the full length of the softened-water channel, with grids located so that the coagulant can be added just before the water enters each set of two basins, or just after it leaves the last two basins on its way to the filters. The grids are of copper pipe with special composition valves and fittings, and are perforated with ¼-in. holes, 18 in. from center to center each way.

It has been found desirable to be able to add coagulant at two different places at the same time, and, while this can be accomplished with the work as built, it is impossible to tell just how much coagulant is being added at each grid. To overcome this difficulty, a rearrangement of the coagulant piping is to be made, so that the discharge from each grid can be measured accurately.

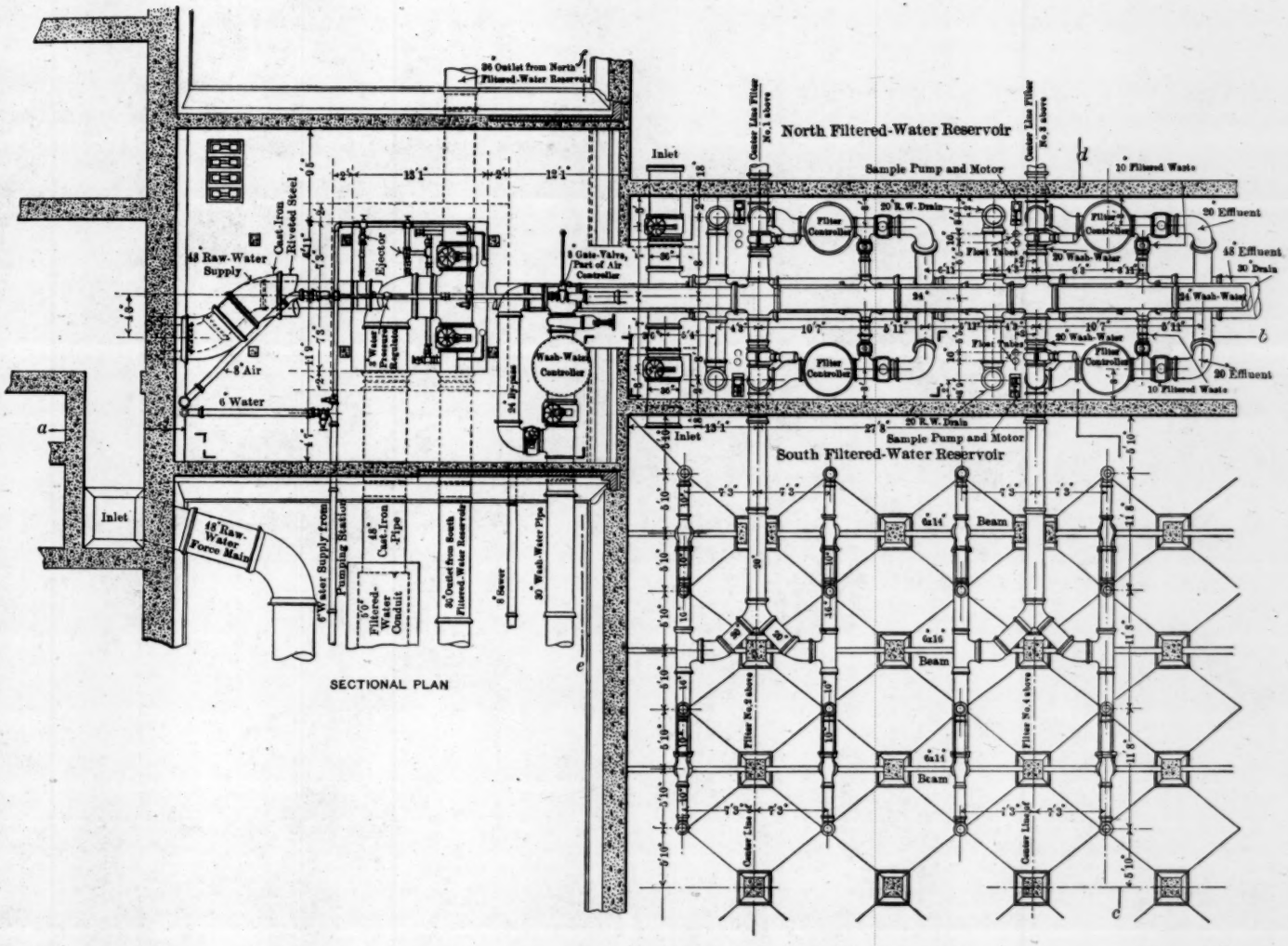
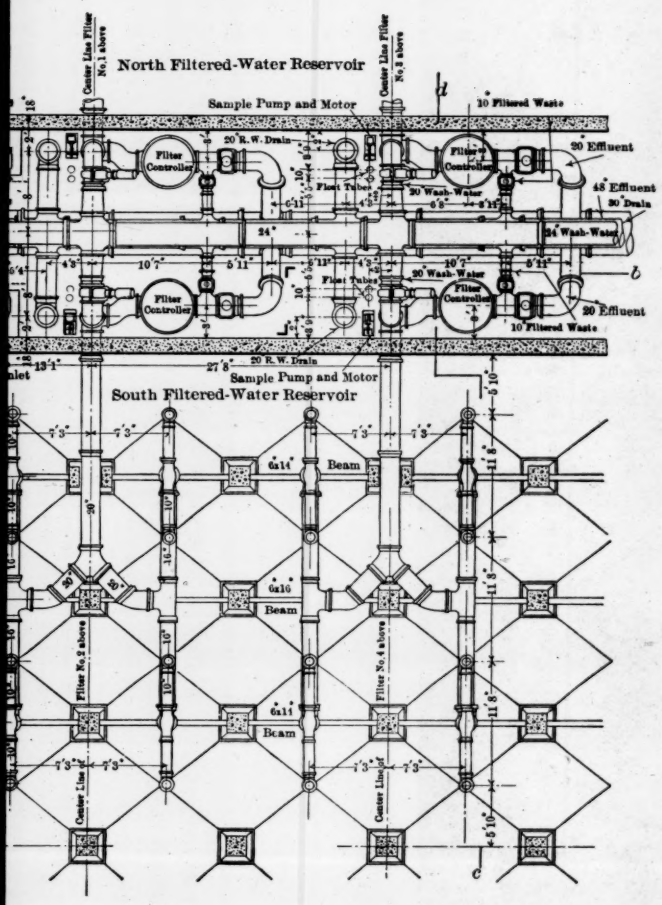
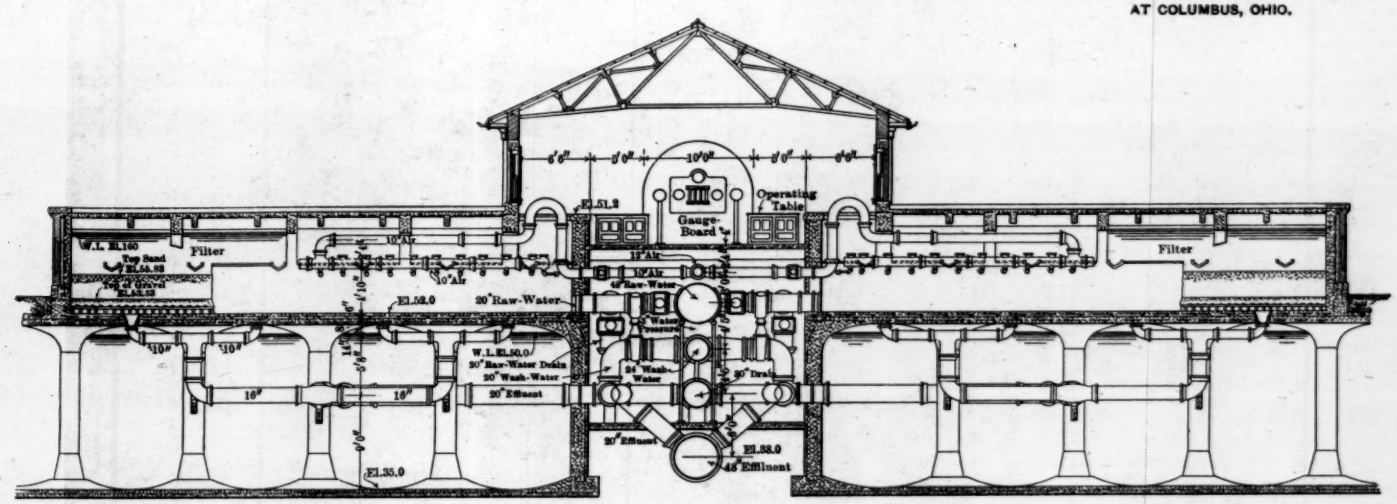
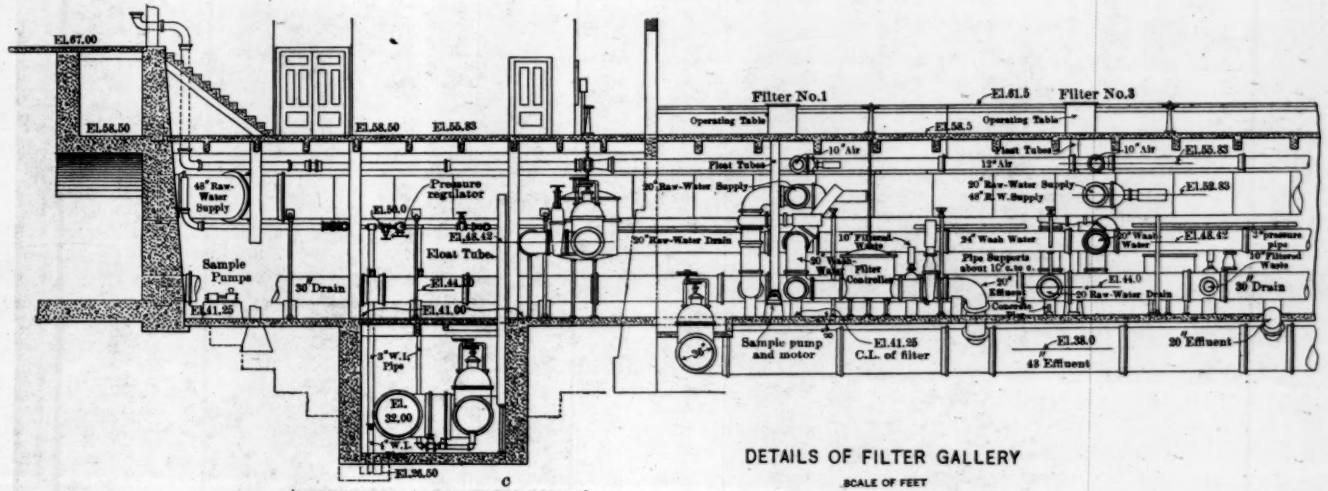

36" Outlet from North Filtered-Water Reservoir
North Filtered-Water Reservoir
Inlet
Center Line Filter No. 1 above
Center Line Filter No. 8 above
Sample Pump and Motor
10" Filtered Waste
20" Effluent
20" R.W. Drain
Filter Controller
Float Tubes
20" Wash-Water
48" Effluent
30" Drain
24" Wash-Water
48" Raw-Water Supply
Cast-Iron Riveted Steel
Ejector
8 Gate-Valves, Part of Air Controller
5" Water Pressure Regulator
Wash-Water Controller
24" by-pass
8" Air
6" Water
a
b
c
d
e
f
Inlet
48" Raw-Water Force Main
6" Water Supply from Pumping Station
48" Cast-Iron Pipe
Filtered-Water Conduit
36" Outlet from South Filtered-Water Reservoir
6" Sewer
30" Wash-Water Pipe
South Filtered-Water Reservoir
Beam
Filter No. 5 above
Filter No. 4 above
Center Line
SECTIONAL PLAN
W.L. El. 160
Top Sand El. 58.83
Top of Gravel El. 55.33
Filter
El. 67.00
El. 58.50
48" Raw-Water Supply
Sample Pumps
El. 41.25

PLATE XVIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.




SECTION ON *c-d*




SECTIONAL ELEVATION ON *a-b*

DETAILS OF FILTER GALLERY

SCALE OF FEET

0 4 8 12 16 20

As mentioned previously, provision has been made for admitting small quantities of raw water to the softened water, prior to filtration, in order to eliminate traces of caustic alkalinity. A 24-in. vitrified raw-water pipe, connecting with the adjustable settling-basin weir in the head-house, is embedded in and extends the full length of the main dividing wall and has four outlets, controlled by sluice-gates, for admitting water to the softened-water channel. At each expansion joint in the wall, a short length of riveted steel pipe was used in place of vitrified pipe.

The lower conduit or channel in the main dividing wall serves as a blow-off drain for emptying the basins. This blow-off conduit is also connected with the drain chambers in the basins, so that the upper 10 or 12 ft. of water in a basin can first be drawn off to the diverting chamber and raw-water suction well, and re-pumped to the other basins before the basin is drained out at the bottom. A 10-in. flushing main is hung from the top of the blow-off conduit, a branch line with several 2½-in. hose-valves extending out into each basin.

*Gate-House.*—The main dividing wall is surmounted by a long brick gate-house extending practically the full length of the dividing wall. In addition to the doors at each end, the gate-house may be reached by a spiral staircase and underground passageway connecting with the passageway at the foot of the stairway in the substructure of the head-house. For raising and lowering the wooden gates controlling the flow of water in the softened-water channel, two 1-ton, Case, hand, traveling cranes have been provided.

## Filter Gallery.

The filter gallery is in the wing of the main building east of the head-house, with the filter tanks ranged on either side of the gallery and supported on the roof of the filtered-water reservoirs. Between the filters there is a reinforced concrete operating floor, below which, and between the walls of the filtered-water reservoirs, is the pipe gallery.

*Filter Tanks.*—The present installation includes ten filters, the details of which are shown on Plate XIX, each having a normal capacity of 3 000 000 gal. per 24 hours. The filter tanks are of concrete heavily reinforced, each being constructed as a monolith. Their inside dimensions are 26 ft. 2 in. wide, 46 ft. 8 in. long, and 8 ft. 10½

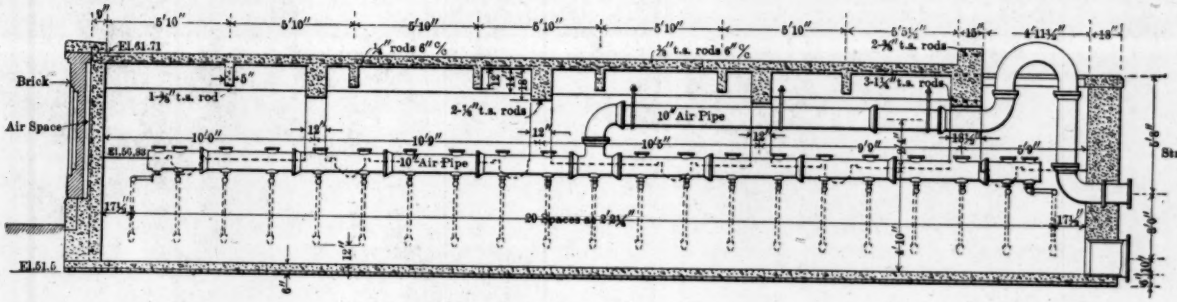
in. deep at the center. Each has a net filtering area of 1 088.9 sq. ft., or 0.025 acre. The filters are designed on the basis of a normal rate of filtration of 2 gal. per sq. ft. per min., but can be operated at a rate 50% greater than the normal, if desired.

Extending down the middle of each tank there is a central gutter, 1 ft. 10 in. wide and 4 ft. 10 in. deep, which divides the filter into two separate parts. On each side of and connecting with the central gutter there are six lateral gutters, 7 ft. 9 in. from center to center. The edges of these lateral gutters, for a distance of 3 ft. 2 in. back from the central gutter, are raised so that no water will flow over them at these points, thereby reducing the quantity of wash-water which the lateral gutters will have to carry, and tending to produce a more uniform rate of discharge of the wash-water from the surface of the filter.

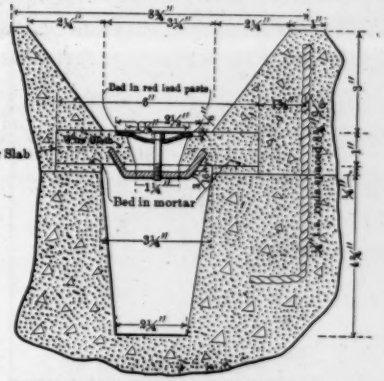
*Strainer System.*—The strainer system of each filter is divided into eight units, the water passages of each unit consisting of a series of lateral channels connecting with a main collector and built monolithic with the floor of the tank. The strainers are held in slabs of fine concrete, the slabs being constructed in separate moulds and then bedded in mortar on the walls separating the water passages. The strainer slabs are held down by prisms or ridges of concrete, built in place, lapping over the edges of the strainer slabs and anchored to the floor of the tank by bent twisted-steel rods. The strainers consist of circular brass plates, No. 16, B. & S. gauge, depressed at the center and pierced with 45 holes, $\frac{1}{16}$ in. in diameter. Each strainer is bedded in a thin paste of red lead, and is held in place by a brass bolt and a brass clip, the clip in turn being held in the strainer slab. There are 2 048 strainers in each filter, $8\frac{3}{4}$ in. from center to center each way, the total area of the holes in the strainer plates in one filter amounting to 1.96 sq. ft., or 0.18% of the filtering area. The strainer system was designed for the application of wash-water at an average rate of 8 gal. per sq. ft. per min. under a net head of about 3 ft., but a maximum rate of 10 gal. per sq. ft. per min. can be obtained, if desired. The effluent piping below the filter is arranged so that the friction loss from the outlet at the center of each of the eight units to the beginning of the main effluent pipe is the same.

*Air System.*—In addition to water, air can be used in washing the filters. A main air pipe of cast iron, 10 in. in diameter, is supported above the central gutter, and, from outlets in the bottom, branch pipes

PLATE XIX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



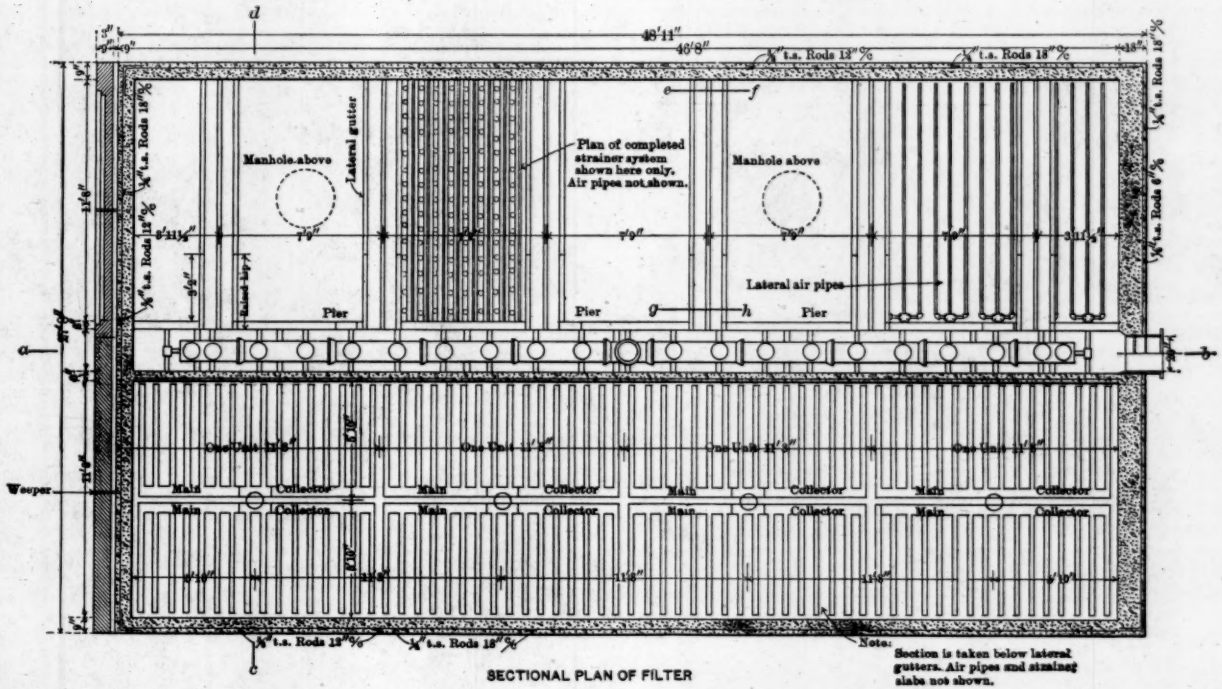

SECTION ON *a-b*



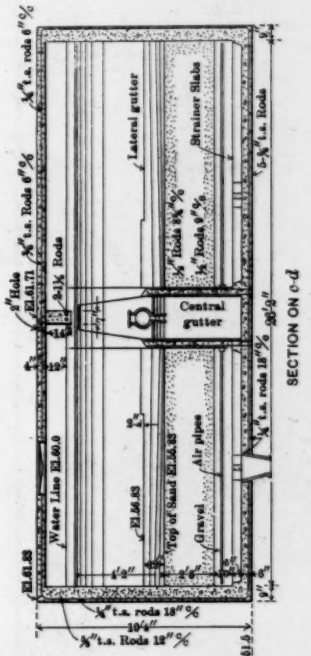

SECTION THROUGH LATERAL COLLECTOR OF STRAINER SYSTEM

SCALE OF INCHES

SCALE OF FEET




SECTIONAL PLAN OF FILTER




SECTION ON *c-d*

DETAILS OF FILTERS

extend down through the walls of the central gutter and connect with the lateral air pipes in the filter. These lateral pipes, which are 8¾ in. from center to center and are supported above the ridges holding down the strainer slabs, are 1 in. in outside diameter, and are drilled on the under side with ⅛-in. holes 8¾ in. from center to center. All the air pipes except the 10-in. main are of brass. The air system was designed for a maximum rate of 3 cu. ft. of free air per sq. ft. per min.

*Filtering Materials.*—The filter gravel, which was screened and washed, is placed in four layers, graded in size, the coarsest, No. 1, being at the bottom. The sizes and thicknesses of the layers of gravel are given in Table 8. The material was brought from Cape May, N. J.

TABLE 8.—FILTER GRAVEL.

| | Size. | Thickness. |
|---|---|---|
| No. 1 | ½ in. to 1 in. | 2 in. |
| No. 2 | ¼ in. to ½ in. | 2 in. |
| No. 3 | ⅛ in. to ¼ in. | 3 in. |
| No. 4 | 1/16 in. to ⅛ in. | 3 in. |

The filter sand, which is supported by the filter gravel, has a total thickness of 2 ft. 6 in. The material is a crushed sandstone, screened and washed, and was obtained from the Millwood White Sand Company, of Millwood, Ohio. The analysis of the sand is given in Table 9.

TABLE 9.—FILTER SAND.

| | |
|---|---|
| Effective size | 0.415 mm. |
| Uniformity coefficient | 1.36 |
| Amount finer than 0.2 mm | 0.15 per cent. |
| Amount finer than 0.25 mm | 0.52 per cent. |
| Amount finer than 0.8 mm | 95.0 + per cent. |
| Amount finer than 1.0 mm | 98.5 + per cent. |
| Specific gravity | 2.63 |
| Silica ($Si O_2$) | 94.5 per cent. |
| Lime (Ca O), finer than 0.36 mm | 1.43 per cent. |
| Iron ($Fe_2 O_3$) | 0.5 per cent. |

*Pipe Gallery and Operating Floor.*—The arrangement of the pipe gallery is shown on Plate XVIII. The main piping is of cast iron, with the exception of the 48-in. raw-water supply, which is of riveted steel. It might be well to state that in the filter gallery the pipes supplying water to the filters for filtration are called raw-water supply pipes, although normally they carry softened, settled water. This name was adopted solely in order to avoid confusion in the operation of the

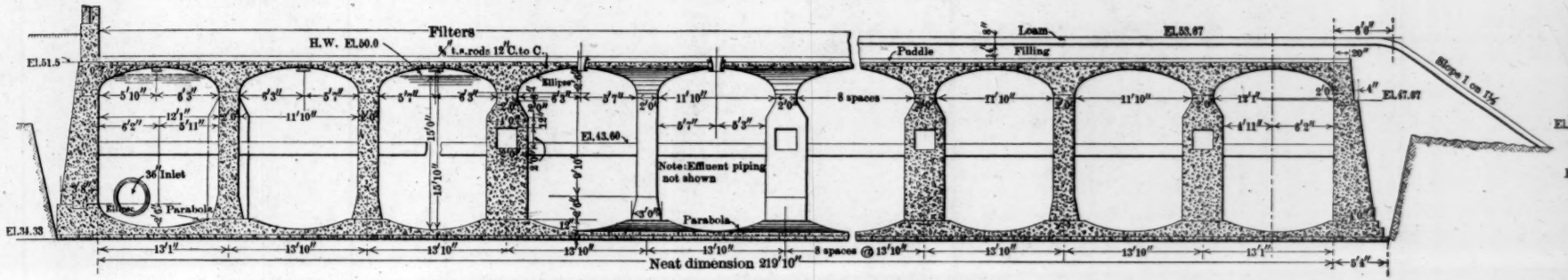
filters, and, for general purposes, was considered better than the term influent. The small piping is of wrought-iron, brass, or lead, depending on the service. The valves used in operating the filters are all flanged, and are operated hydraulically.

On the operating floor in front of each filter there is a marble operating table fitted with four-way cocks, with extension stems and lever handles, for controlling the opening and closing of the hydraulic valves. An indicator in front of each lever handle shows the position of the valve, whether open, closed, or partly open. A loss-of-head gauge, mounted on the table, shows the elevation of the water on the filter and in the effluent pipe, and also the difference between the two, or the loss of head. Samples of the settled water and of the filtered water can be pumped by two small electrically-driven centrifugal pumps into the bowl on the operating table.

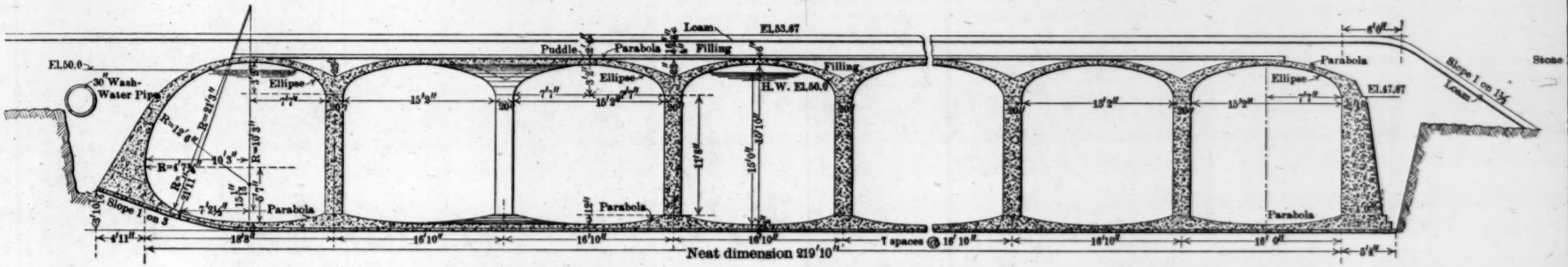
The discharge of each filter is controlled by a filter controller which maintains automatically a uniform rate of filtration. The controller is of the closed type, is self-contained, requiring no auxiliary device for its operation, was designed especially for the Columbus works, and operates under a net loss of head of about 1 ft. The controller is adjustable by means of an operating stand on the floor above, and has a capacity ranging from a minimum of 1 000 000 to a maximum of 4 500 000 gal. per 24 hours.

Water for washing the filters is supplied from an elevated tank located between the pumping station and the purification works. The rate of application of the wash-water can be controlled by a wash-water controller located in the main wash-water pipe at the west end of the pipe gallery, or it can be controlled by hand at the operating table. The controller is similar in design to the filter controller, and has a maximum capacity of 16 000 000 gal. per 24 hours, with a net loss of head of about 1 ft.; the dial on the operating stand, however, is graduated to read the rate of application of the wash-water to the filters in gallons per square foot per minute.

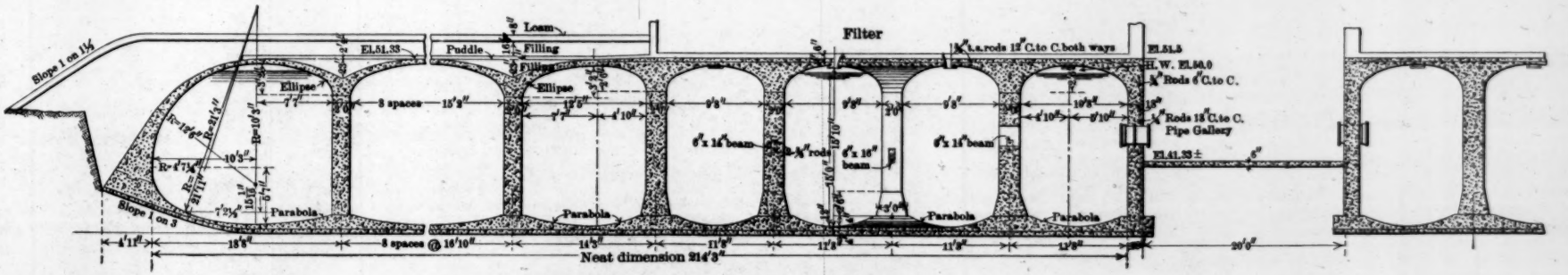
The equipment for supplying air for washing the filters has already been mentioned. The rate of application of the air wash is controlled by a gate-valve in the main air pipe at the west end of the gallery. By means of the pressure-reducing valve, a constant pressure is maintained on the up-stream side of the gate-valve, and, by opening or closing the main valve, from the operating stand on the floor above,




SECTION EAST AND WEST THROUGH FILTERS, LOOKING NORTH

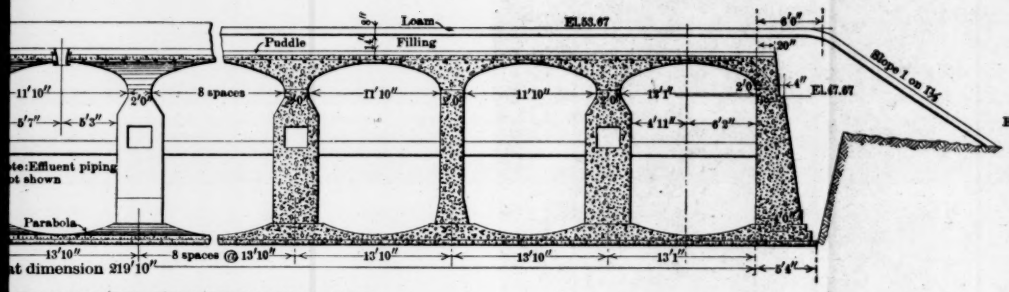



SECTION EAST AND WEST, SOUTH OF FILTERS, LOOKING NORTH

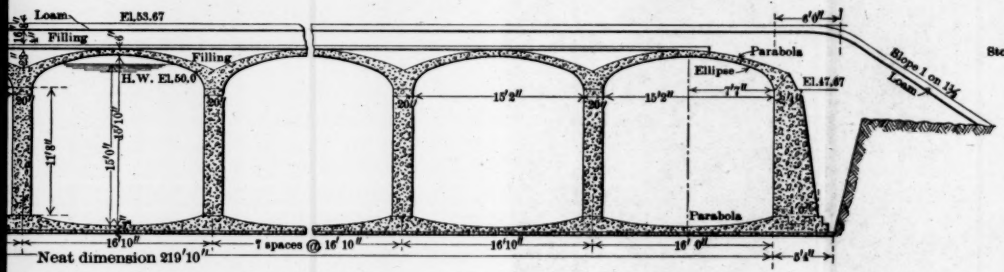



SECTION NORTH AND SOUTH, LOOKING WEST

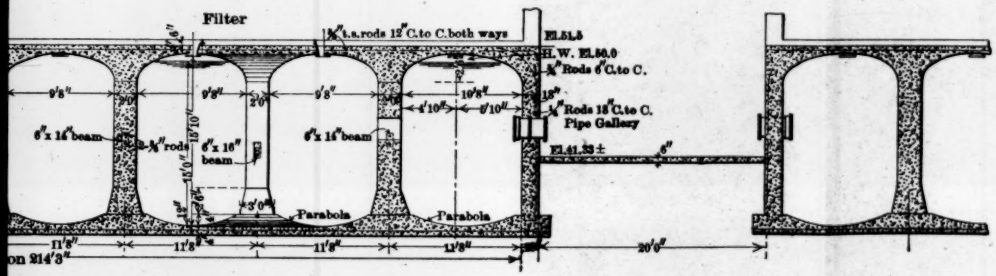
PLATE XX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



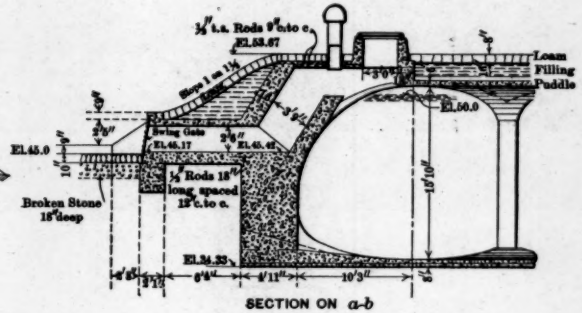

THROUGH FILTERS, LOOKING NORTH



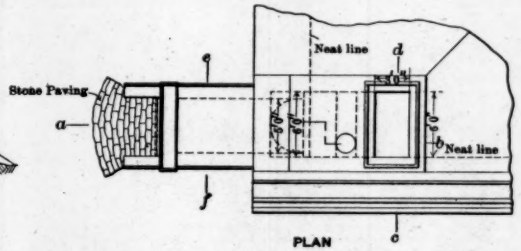

, SOUTH OF FILTERS, LOOKING NORTH



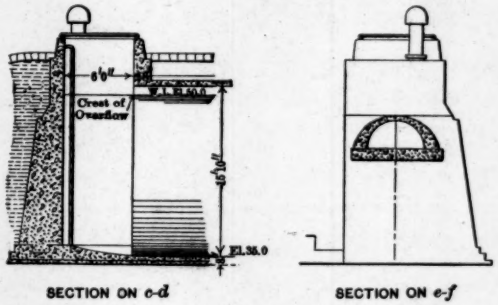

AND SOUTH, LOOKING WEST




SECTION ON *a-b*




PLAN




SECTION ON *c-d*

SECTION ON *e-f*

DETAILS OF SOUTH FILTERED-WATER RESERVOIR

SCALE OF FEET
0 4 8 12 16 20

the flow of air is controlled. The dial on the operating stand is graduated to indicate the rate of application of the air to the filters in cubic feet per square foot per minute.

At the west end of the filter gallery there is a gauge board on which is mounted a recording gauge showing the level of the water in the wash-water tank, a recording gauge showing the pressure of the air in the air tanks in the saturator-house, and a gauge showing the pressure of the air in the main air pipe on the down-stream side of the air-controlling valve. Mounted on this board, also, there are four glass tubes through which samples of the river water, softened water, settled water, and filtered water can be observed, being supplied by small pumps located in the pipe gallery below. These pumps also supply samples of the four kinds of water to the laboratories above.

## Filtered-Water Reservoirs.

To compensate for the hourly and also daily variation in the rate of pumping into the distribution system, the city being on direct service, as previously mentioned, two covered filtered-water reservoirs have been constructed. The reservoirs, throughout, are of concrete, the construction being of the groined-arch type, in general similar to that adopted for covered reservoirs elsewhere. Each reservoir is 219 ft. 10 in. long, 214 ft. 3 in. wide, and 15 ft. 10 in. deep, and, with water 15 ft. in depth, has a capacity of approximately 5 000 000 gal., the two having a total of 10 000 000 gal., equal to about 8 hours' supply when the purification works are operated at a rate of 30 000 000 gal. per 24 hours. The plan of the reservoirs is shown on Plate IX and longitudinal and cross-sections of the south reservoir on Plate XX.

*Floor.*—The floor, which has a minimum thickness of 8 in. midway between the piers, was built in two layers, the lower layer having a thickness of 4 in. throughout. The joints were made on the diagonal lines between the piers, the joints in the upper layer lapping over those in the lower layer by about 3 or 4 in.

*Walls.*—The walls adjacent to and forming the sides of the pipe gallery are built with plumb faces, and are reinforced both vertically and longitudinally. The east wall of each reservoir is plumb on the inside and battered on the outside, and is of such design that it will serve as a future dividing wall when the works are extended. The remaining length of wall, except immediately under the west walls

of Filters Nos. 1 and 2, has a section similar to one-half of the cross-section of a large aqueduct.

*Vaulting.*—Over about three-fourths of the area of the reservoirs the groined arches have a clear span of 15 ft. 2 in., a rise of 3 ft. 2 in., and a thickness of 6 in. at the crown, the piers being 20 in. square. Over the remaining fourth of the area, the span of the arches is reduced, being 9 ft. 8 in. one way and 11 ft. 10 in. the other, with piers 2 ft. square. The vaulting over this area is level on top, is 8 in. thick at the crown of the arch, and is reinforced with ⅝-in., square, twisted-steel rods 12 in. from center to center each way. The filter tanks are built on top of this portion of the vaulting, the piers being located so as to come under the walls and central gutters of the tanks, where the loads are the heaviest. The vaulting is covered with a 4-in. layer of clay puddle, with 2 ft. of filling above.

*Baffle Walls.*—The baffle wall in each reservoir is 6 in. thick, reinforced with ⅝-in. square twisted-steel rods 18 in. from center to center each way, and extends from the floor to the vaulting. The walls are keyed into the piers, the section between each two adjacent piers being built as a monolith.

*Pipe Connections and Overflows.*—Filtered water is admitted to each reservoir at the west end of the pipe gallery, and is drawn off on the opposite side of the baffle wall from the inlet, into a 36-in. filtered-water pipe. The two filtered-water pipes are brought together in a valve chamber where they connect with a 48-in. pipe opening into the 5-ft. filtered-water conduit running to the filtered-water suction well north of the pumping station.

Each reservoir is provided with an overflow, the crest being at Elevation 50.0, or 10 ft. below the normal water line in the filters.

## Offices and Laboratories.

That portion of the wing of the main building east of the head-house and lying between the head-house and the filter gallery is two stories in height, with a basement below, and at this point the main entrance to the purification works is located. The first floor is on the same level as the floor of the filter gallery, and contains a locker-room, a lavatory, and a storeroom. In the storeroom is located a machine for producing gas for use in the laboratories. The general office, a private office, the bacteriological and chemical laboratories, and a preparation-

PLATE XXI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

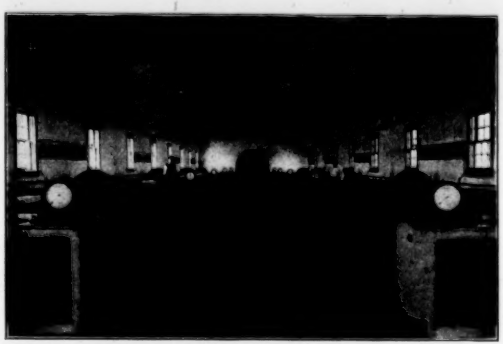


FIG. 1.—INTERIOR OF FILTER GALLERY.

FIG. 2.—VIEW OF CHEMICAL MIXING ROOM.

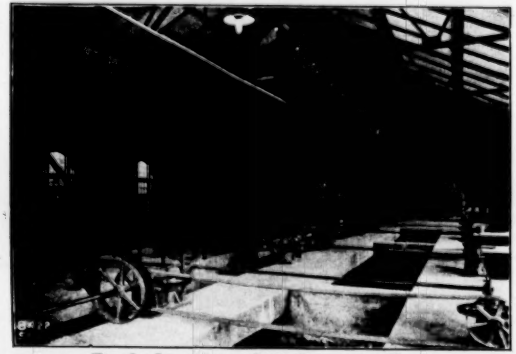


FIG. 3.—INTERIOR OF LIME SATURATOR HOUSE.

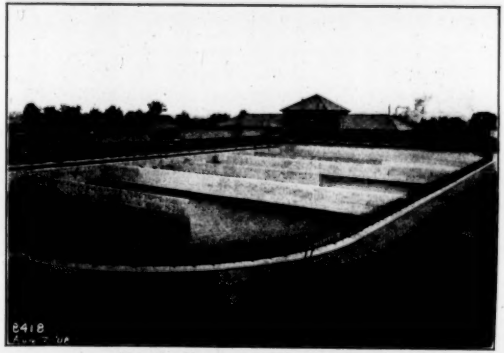


FIG. 4.—VIEW OF SETTLING BASINS.

room, are on the second floor. The basement is in reality the west end of the pipe gallery, and through it pass the pipe lines connecting the substructure of the head-house with the filter gallery.

### Wash-Water Tank, Shelter, and Tool-House.

Midway between the pumping station and saturator-house there is an elevated tank, with a shelter and tool-house below.

*Wash-Water Tank.*—The tank is 42 ft. in diameter, inside, and 11 ft. deep, and with water 10 ft. in depth has a capacity of 104 000 gal., sufficient to wash two filters, one immediately after the other, at a rate of 8 gal. per sq. ft. per min. for a period of 7 min. each, making allowance for the quantity supplied by the wash-water pump during the period of washing. The floor of the tank is at Elevation 77.0, about 24 ft. above the ground and 20 ft. 2 in. above the top of the gutters in the filters. The tank is of reinforced concrete, with 12-in. walls, and is supported on concrete columns.

*Shelter and Tool-House.*—The space below the tank is divided into two floors; the upper floor contains a storeroom, and also a lavatory and locker-room for the use of the laboring force employed in unloading coal and chemicals, cleaning the intake screens and settling basins, cutting grass, etc. The ground floor is used as a small stable, provision being made for keeping two horses; this floor is used also as a storehouse for tools.

### Construction of Buildings.

The walls of the main building and gate-house are of brick, faced outside with red pressed brick. In the gate-house, and in the saturator-house, storage-house, and third floor of the head-house of the main building, the walls are lined inside with hard red brick; in the other parts of the main building the walls are finished with hard wall plaster. The ceilings in the offices, laboratories, preparation-room, and third floor of the head-house are plastered on expanded metal fastened to the lower chords of the roof trusses. The water-tables, belt-courses, window-sills, lintels, and copings are of concrete of the same character as that used in the pumping station.

The floors, columns, and stairways are of reinforced concrete. The roof trusses are all of steel, the covering being of slate laid on 3-in., hollow, terra cotta tile. In the gate-house, saturator-house, storage-house, and filter gallery, the tile is plastered on the under side. The

buildings are lighted throughout with electricity, and the main building is heated with steam.

### Concrete.

In the construction of the work, concrete, both plain and reinforced, was used extensively, the total quantity in the pumping station, purification works, and adjacent structures amounting to 39 560 cu. yd. The average price paid for the above amount was $7.27 per cu. yd. The relative volumes of cement, sand, and ballast in each mixture of concrete, and the corresponding character of work in which the mixture was used, were as follows:

1:2:4.—Water-tables, belt-courses, window-sills, lintels, etc.; filter, solution, dissolving, and wash-water tanks; reinforced floors, roofs, stairways, and steps.

1:2½:5½.—Columns in buildings and piers of wash-water tank; filtered-water reservoirs, lime saturators, mixing tanks, and substructure of head-house; settling basins, except lateral dividing and baffle walls; walls in general, conduits, and miscellaneous small structures.

1:3:7.—Lateral dividing and baffle walls of settling basins; footings, and foundations for machinery and chimney.

The specifications permitted the engineer to change the relative volumes of the sand and ballast in each mixture, while keeping the aggregate of the two the same, and this was sometimes done, but in general the proportions as given above were used. Ordinarily, the concrete was mixed very wet.

The ballast was screened into three sizes: No. 1, ¼ to ¾-in.; No. 2, ¾ to 1½-in.; and No. 3, 1½ to 3-in. In ordinary work a mixture of the three sizes was used, but, in a considerable amount of the reinforced work, the No. 3 ballast was omitted, and frequently only the No. 1 ballast was used, particularly in thin vertical work and in the lower parts of beams and horizontal reinforced work, in order to insure a good bedding of the square, twisted-steel rods.

Expansion joints were built throughout the work where necessary. Where subject to the action of water which had been treated with lime and soda, the expansion joint consisted of a tongue and groove in the concrete, with a steel plate bedded and anchored on one side of the joint and greased on the other; in other places the tongue and groove only was used.

### Connections to City.

From the pumping station the purified water is pumped to the city through two lines of 36-in. cast-iron force mains to a point opposite the old West Side Pumping Station, where connections are made with the existing distribution system, a Venturi meter being placed on each connection. A 36-in. branch also connects with the suction wells at the old pumping station, so that filtered water can be pumped from this station in case of a shut-down at the new pumping station, the two 36-in. force mains being so arranged at the new pumping station that they can be operated as gravity mains from the water purification works. While it is not planned to run the old station, this method of operation was very serviceable in furnishing the city with a partial supply of filtered water before the new pumping station was entirely ready for use.

The main approach to the new works from the city is by the Dublin Pike, a country road, in which the force mains are laid. As the road was in bad condition, and as one or two stretches were sometimes under water during periods of flood in the river, the opportunity was taken to improve it at the time the force mains were laid, by regrading it, macadamizing the surface, and fencing it along the embankment portions.

### Cost of Work.

Table 10 gives the total cost of the work in such detail that further description is hardly needed, and Table 11 gives the unit costs of the main features of the work. No attempt has been made to distribute the cost of engineering over the several parts of the work, as it is believed that the figures are of greater value as presented than if they included a percentage for engineering.

### Contractors and Progress of Work.

The first bond issue was authorized in November, 1904, and the preparation of the first drawings and specifications was commenced shortly after. The purification works were placed under contract in June, 1905, the machinery and equipment for the pumping station in September, 1905, the pumping station and connections in July, 1906, and the force mains connecting with the city in October, 1907. Raw water was first pumped to the purification works on July 2d, 1908, and

TABLE 10.—Cost of Scioto River Pumping Station and Water Purification Works and Work Connected Therewith.

| | | | | |
|---|---|---|---|---|
| Land.....58 acres | | | | $48 410 |
| Railroad Spur to Purification Works and Pumping Station. | | | | |
| Track.....2 760 lin. ft. | | $5 740 | | |
| Culvert, 6 by 6-ft.....50 lin. ft. | | 810 | | |
| Track Scales. | | | | |
| Foundations | $1 060 | | | |
| Scales and track | 1 860 | 2 920 | | |
| Bridge.....115 lin. ft. | | | | |
| Substructure | 500 | | | |
| Superstructure | 3 530 | 4 030 | $13 500 | |
| Roads, Walks, Grading, and Drainage of Grounds. | | | | |
| Roads, walks, and grading | | 7 620 | | |
| Drainage of grounds | | 770 | 8 390 | |
| Raw-Water Supply Connections from River to Pumping Station. | | | | |
| Intake, river to gate-house | | 2 600 | | |
| Gate-House. | | | | |
| Substructure.....14 400 cu. ft. | 5 360 | | | |
| Superstructure.....5 160 cu. ft. | 1 230 | | | |
| Screening equipment | 1 740 | 8 330 | | |
| Intake conduit, 5-ft.....180 lin. ft. | | 3 540 | | |
| Raw-water suction well.....8 200 cu. ft. | | 1 440 | | |
| 30-in. suction pipes to pumping station, 110 lin. ft. | | 3 720 | | |
| Ground-water drains | | 1 250 | 20 880 | |
| Filtered-Water Supply Connections from Purification Works to Pumping Station. | | | | |
| 5-ft. Filtered-water conduit.....300 lin. ft. | | 3 540 | | |
| Filtered-water suction well.....14 480 cu. ft. | | 2 760 | | |
| 42-in. suction pipes to pumping station..50 lin. ft. | | 1 050 | 7 350 | |
| 48-In. Raw-Water Force Main and Meter. | | | | |
| 48-in. Force main.....550 lin. ft. | | 7 800 | | |
| 48-in. Venturi meter and vault | | 3 670 | 11 470 | |
| Main Drain and Branches. | | | | |
| Drains. | | | | |
| Branch drain from settling basins, 3-ft. by 4 ft. 6-in.....250 lin. ft. | 1 440 | | | |
| Branch drain from saturator house, 30-in., 190 lin. ft. | 1 440 | | | |
| Branch drain, boiler blow-off, 4-in..150 lin. ft. | 60 | | | |
| Main drain, twin section, 3-ft. by 4 ft. 6-in., to diverting chamber.....350 lin. ft. | 3 410 | | | |
| Main drain, 3-ft. by 4 ft. 6-in., diverting chamber to river outlet.....280 lin. ft. | 2 020 | | | |
| River outlet | 310 | 8 680 | | |
| Diverting Chamber and Conduit. | | | | |
| Diverting chamber | 1 410 | | | |
| Diverting conduit, 3 ft. 6-in.....80 lin. ft. | 450 | 1 860 | 10 540 | |
| Sewers and Sewage Disposal. | | | | |
| Sewers. | | | | |
| Main sewer, 8-in., purification works to drop-manhole.....630 lin. ft. | 760 | | | |
| Branch sewer to pumping station, 6-in., 160 lin. ft. | 100 | | | |
| Drop-manhole | 370 | | | |
| Inverted siphon, 6-in .....570 lin. ft. | 560 | 1 790 | | |
| Sewage Disposal. | | | | |
| Septic Tank | 1 080 | | | |
| Filters | 1 080 | | | |
| Drains to river | 200 | 2 310 | 4 100 | |
| Carried forward | | | $76 230 | $48 410 |

TABLE 10.—(*Continued.*)

| | | | | |
|---|---|---|---|---|
| Brought forward | | | $76 230 | $48 410 |
| MISCELLANEOUS PIPING. | | | | |
| Station Water Supply | | $680 | | |
| By-pass to filtered-water suction well, 16-in., 90 lin. ft. | | 410 | | |
| Suction to flushing pump, 12-in., 70 lin. ft. | | 110 | | |
| Water supply, 6-in., pumping station to purification works, 350 lin. ft. | | 220 | | |
| Wash-water, 10-in., pumping station to wash-water tank, 140 lin. ft. | | 170 | | |
| Hydrant connections to force mains | | 220 | 1 810 | |
| TELEPHONE, ELECTRIC AND STEAM CONDUITS AND MAINS. | | | | |
| Electric main, pumping station to intake gate-house | | 160 | | |
| Telephone conduit, 2-duct, Dublin Pike to pumping station, 180 lin. ft. | | 170 | | |
| Telephone and electric conduit and mains, pumping station to purification works | | 1 440 | | |
| Steam main, pumping station to purification works | | 380 | 2 150 | 80 190 |
| PUMPING STATION. | | | | |
| Building, 1 273 300 cu. ft. | | | | |
| Substructure, 337 000 cu. ft. | | 44 830 | | |
| Superstructure, 936 300 cu. ft. | | 83 660 | 128 490 | |
| Chimney. | | | | |
| Substructure, 32 ft. deep | | 2 690 | | |
| Superstructure, 8 ft. diam., 160 ft. high | | 5 380 | 8 070 | |
| Machinery and Equipment. | | | | |
| Pumps. | | | | |
| Vertical, triple-expansion pumping engines, 2 | $160 110 | | | |
| Engine-driven centrifugal pumps, 2 | 23 330 | | | |
| Flushing pump | 3 500 | | | |
| Wash-water pump | 2 640 | | | |
| Sump pump | 300 | 189 880 | | |
| Electric generating units and switch-board, 2 | | 10 500 | | |
| Boilers and Accessories. | | | | |
| Boilers, 1 200 h.p. | 16 700 | | | |
| Masonry boiler flue | 1 890 | | | |
| Boiler feed pumps, 2 | 1 950 | | | |
| Surface condenser and vacuum pump | 4 110 | | | |
| Open feed-water heater | 1 060 | 25 710 | | |
| Piping. | | | | |
| Cold-water piping | 17 030 | | | |
| Steam, feed and drain piping | 9 880 | 26 910 | | |
| Electric traveling crane | | 4 950 | | |
| Miscellaneous equipment | | 1 030 | 258 980 | 395 540 |
| Carried forward | | | | $524 140 |

TABLE 10.—(*Continued.*)

| | | | | |
|---|---|---|---|---|
| Brought forward | | | | $524 140 |
| WATER PURIFICATION WORKS. | | | | |
| Settling Basins ..... 15 000 000 gal. | | | | |
| Earthwork | | $35 480 | | |
| Roads and walks | | 1 420 | | |
| Fence ..... 1 510 lin. ft. | | 1 420 | | |
| Lining. | | | | |
| Puddle | $16 640 | | | |
| Concrete | 20 370 | | | |
| Stone paving | 3 870 | 40 880 | | |
| Walls. | | | | |
| Main dividing wall ..... 430 lin. ft. | 37 960 | | | |
| Lateral dividing walls ..... 820 lin. ft. | 26 560 | | | |
| Baffle walls ..... 730 lin. ft. | 6 630 | | | |
| Deflectors and drain chambers | 830 | 71 980 | | |
| Piping. | | | | |
| Flushing main and branches | 2 060 | | | |
| Coagulant piping and indicator | 1 260 | 3 320 | | |
| Gate-House. | | | | |
| Superstructure ..... 90 900 cu. ft. | 13 170 | | | |
| Hand traveling cranes ..... 2 | 1 100 | 14 270 | $168 770 | |
| Head-House. | | | | |
| Substructure ..... 92 900 cu. ft. | | | | |
| Earthwork | 380 | | | |
| Concrete | 10 200 | | | |
| Steel reinforcement | 540 | | | |
| Piping, valves, and appurtenances | 2 210 | | | |
| Head-house weirs | 1 010 | | | |
| Iron and steelwork | 330 | 14 670 | | |
| Superstructure ..... 144 000 cu. ft. | | 14 560 | | |
| Equipment in Superstructure. | | | | |
| Dissolving tanks ..... 4 | 900 | | | |
| Slaking tanks ..... 3 | 1 420 | | | |
| Solution tanks ..... 9 | 2 560 | | | |
| Piping, regulators, and appurtenances | 5 610 | 10 430 | 39 660 | |
| Air-Wash Equipment in Head and Saturator Houses. | | | | |
| Air compressor | | 780 | | |
| Air tanks ..... 3 | | 1 960 | | |
| Air controller | | 530 | | |
| Piping | | 230 | 3 470 | |
| Lime-Saturator House. | | | | |
| Lime Saturators ..... 6 | | | | |
| Earthwork | 660 | | | |
| Concrete and brick masonry | 10 360 | | | |
| Steel reinforcement | 2 790 | | | |
| Piping and valves | 2 850 | | | |
| Iron and steelwork | 940 | | | |
| Stirring machinery | 6 810 | 24 410 | | |
| Superstructure ..... 120 300 cu. ft. | | 8 140 | 32 550 | |
| Carried forward | | | $244 450 | $524 140 |

## TABLE 10.—(*Continued.*)

| | | | | |
|---|---|---|---|---|
| Brought forward | | | $244 450 | $524 140 |
| WATER PURIFICATION WORKS (*Continued*). | | | | |
| Mixing Tanks, 2.....1 270 000 gal. | | | | |
| Earthwork | | $4 580 | | |
| Concrete and brick masonry | | 32 440 | | |
| Steel reinforcement | | 2 350 | | |
| Piping, valves and stop planks | | 3 850 | | |
| Iron and steelwork | | 1 010 | 44 230 | |
| Storage House. | | | | |
| Superstructure.....152 500 cu. ft. | | 9 740 | | |
| Apron conveyor | | 3 080 | | |
| Scales and trucks | | 60 | 12 880 | |
| Office and Laboratory. | | | | |
| Substructure. | | | | |
| Earthwork | $500 | | | |
| Concrete | 2 600 | | | |
| Steel reinforcement | 80 | | | |
| Iron and steelwork | 140 | 3 320 | | |
| Superstructure.....46 100 cu. ft. | | 8 220 | | |
| Furniture and Equipment. | | | | |
| Furniture and fittings | 880 | | | |
| Laboratory equipment | 2 860 | 3 740 | 15 280 | |
| Filter Gallery. | | | | |
| Substructure | | 2 250 | | |
| Superstructure.....71 700 cu. ft. | | 8 410 | | |
| Filters.....10 | | | | |
| Concrete and brick masonry | 21 250 | | | |
| Steel reinforcement | 3 430 | | | |
| Ironwork | 410 | | | |
| Strainer systems.....10 890 sq. ft. | 3 740 | | | |
| Air systems.....10 890 sq. ft. | 5 500 | | | |
| Filter gravel.....300 cu. yd. | 2 050 | | | |
| Filter sand.....1 010 cu. yd. | 6 960 | 43 340 | | |
| Operating tables.....10 | | 6 260 | | |
| Filter controllers.....10 | | 8 920 | | |
| Piping and valves | | 29 670 | | |
| Wash-water controller and by-pass | | 2 860 | | |
| Gauge-board, sampling devices, and connections | | 1 000 | 102 710 | |
| Filtered-Water Reservoirs, 2.....10 000 000 gal. | | | | |
| Earthwork | | 29 500 | | |
| Puddle water-proofing on vaulting | | 1 480 | | |
| Concrete | | 57 440 | | |
| Steel reinforcement | | 3 050 | | |
| Piping, valves, and indicators | | 6 700 | | |
| Iron and steelwork | | 130 | 98 300 | |
| Carried forward | | | $517 850 | $524 140 |

## TABLE 10.—(*Continued.*)

| | | | | |
|---|---|---|---|---|
| Brought forward | | | $517 850 | $534 140 |
| WATER PURIFICATION WORKS—(*Continued*). | | | | |
| Wash-Water Tank and Pipe, and Shelter and Tool-House. | | | | |
| Wash-water tank.....104 000 gal. | | | | |
| Foundations | $840 | | | |
| Piers | 650 | | | |
| Tank | 3 090 | $4 580 | | |
| Shelter and tool-house under tank..34 700 cu. ft. | | 6 610 | | |
| Wash-water pipe, 30-in., from tank to purification works.....250 lin. ft. | | 1 960 | 13 150 | |
| Supplies for Preliminary Operation of Works | | | 460 | |
| Expenses Unclassified | | | 1 020 | 532 480 |
| Total Cost of Works, Exclusive of Connections to City, and Exclusive of Engineering | | | | $1 056 620 |
| CAST-IRON FORCE MAINS TO CITY. | | | | |
| 48-in. Venturi meter | | | 4 030 | |
| 36-in. mains.....10 640 lin. ft. | | | 139 370 | |
| 36-in. connection to old West Side pumping station.....180 lin. ft. | | | 4 340 | |
| Connections to distribution system | | | 12 640 | |
| 20-in. and 24-in. Venturi meters | | | 5 340 | |
| Blow-offs | | | 1 120 | |
| Hydrant connections | | | 210 | 167 050 |
| IMPROVEMENT OF DUBLIN PIKE | | | | 13 950 |
| Total Cost, Exclusive of Engineering | | | | $1 237 620 |
| ENGINEERING, 7.75 per cent. | | | | |
| Pay-roll | | | 84 340 | |
| Supplies | | | 6 120 | |
| Expenses | | | 5 490 | 95 950 |
| TOTAL COST | | | | $1 333 570 |

### SUMMARY.

| | |
|---|---|
| Land | $48 410 |
| Work, exclusive of pumping station and water purification works | 76 490 |
| Pumping station | 399 240 |
| Water purification works | 532 480 |
| Total cost of works, exclusive of connections to city and exclusive of engineering | $1 056 620 |
| Connections to city | 181 000 |
| Total cost, exclusive of engineering | $1 237 620 |
| Engineering | 95 950 |
| TOTAL COST | $1 333 570 |

TABLE 11.—UNIT COST OF MAIN FEATURES OF WORK.

| Work. | Capacity. | Total cost. | Unit cost. |
|---|---|---|---|
| *Pumping station building | 1 273 300 cu. ft. | $128 490 | 10.1 cents per cu. ft. |
| †Main buildings, water purification works | 534 600 cu. ft. | 49 070 | 9.2 cents per cu. ft. |
| Settling basins | 15 000 000 gal. | 168 770 | $11 250 per million gallons. |
| Lime saturators | 6 750 000 gal. per 24 hours | 24 410 | 3 620 per million gallons per 24 hours. |
| Mixing tanks | 1 270 000 gal. | 44 230 | 34 800 per million gallons. |
| Filtered-water reservoirs | 10 000 000 gal. | 98 300 | 9 830 per million gallons. |
| Water purification works: | | | |
| Settling basins | 30 000 000 gal. per 24 hours | $168 770 | $5 630 per million gallons per 24 hours. |
| Head-house | | 39 660 | 1 320 |
| Air-wash equipment | | 3 470 | 120 |
| Lime-saturator house | | 32 550 | 1 090 |
| Mixing tanks | | 44 230 | 1 470 |
| Storage house | | 12 880 | 430 |
| Office and laboratory | | 15 280 | 510 |
| Filter gallery | | 102 710 | 3 420 |
| Filtered-water reservoirs | | 98 300 | 3 280 |
| Wash-water tank, pipe, and shelter | | 13 150 | 440 |
| Supplies for preliminary operation | | 460 | 20 |
| Expenses unclassified | | 1 020 | 30 |
| | | $532 480 | $17 750 |

*Includes superstructure and substructure of building.
†Includes superstructure of head-house, saturator house, storage house, office and laboratory, and filter gallery.

TABLE 12.—WATER PURIFICATION WORKS.

| Day of Month. | Temperature of air, in degrees Fahr. | Temperature of water, in degrees Fahr. | Rainfall, in inches. | Volume of Water. | | Filter Data. | | | | | Applied Chemicals. | | | | | | Color. | | Turbidity. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Pounds. | | | Grains per gallon. | | | | | | | |
| | | | | Pumped, million gal. | Filtered, million gal. | Number used. | Hours in service, average. | Loss of head, maximum, in feet. | Wash-water, percentage. | Use of air. | Lime. | Soda ash. | Coagulant. | Lime. | Soda ash. | Coagulant. | River water. | Filtered water. | River water. | Filtered water. | Free carbonic acid, river water. |
| 1 | 24 | 55 | 0.00 | 14.9 | 13.2 | 9 | 21.0 | 2.5 | 1.3 | + | 30 063 | 16 440 | 0 | 14.1 | 7.7 | 0.00 | 35 | 3 | 4 | 0 | 3 |
| 2 | 22 | 33 | 0.00 | 14.6 | 14.1 | 9 | 20.3 | 2.7 | 1.9 | + | 28 290 | 15 780 | 0 | 13.6 | 7.6 | 0.00 | 42 | 2 | 4 | 0 | 3 |
| 3 | 38 | 35 | 0.01 | 13.6 | 12.7 | 9 | 16.6 | 3.2 | 1.4 | + | 26 782 | 14 760 | 0 | 13.7 | 7.6 | 0.00 | 27 | 1 | 5 | — | 3 |
| 4 | 42 | 37 | 0.21 | 14.5 | 14.1 | 10 | 17.7 | 2.6 | 1.6 | + | 27 765 | 15 840 | 0 | 13.4 | 7.6 | 0.00 | 27 | 2 | 5 | 0 | 3 |
| 5 | 48 | 38 | 0.17 | 15.4 | 13.9 | 10 | 18.3 | 2.8 | 1.0 | + | 30 780 | 16 988 | 595 | 14.0 | 7.7 | 0.28 | 37 | 2 | 7 | 0 | 5 |
| 6 | 38 | 37 | 0.02 | 15.0 | 14.5 | 10 | 19.1 | 7.0 | 1.4 | + | 31 085 | 13 860 | 819 | 14.5 | 6.5 | 0.38 | 16 | 1 | 8 | 0 | 4 |
| 7 | 20 | 33 | tr. | 15.5 | 15.2 | 10 | 20.2 | 7.0 | 1.6 | + | 29 845 | 15 300 | 791 | 13.5 | 6.9 | 0.37 | 18 | 2 | 6 | 0 | 8 |
| 8 | 32 | 32 | 0.00 | 14.9 | 15.1 | 10 | 20.0 | 6.9 | 1.6 | + | 29 704 | 16 680 | 714 | 13.9 | 7.8 | 0.34 | 13 | 0 | — | 0 | 9 |
| 9 | 31 | 31 | 0.02 | 16.4 | 14.7 | 10 | 20.4 | 6.7 | 2.0 | + | 32 101 | 18 360 | 336 | 13.7 | 7.8 | 0.14 | 9 | 1 | 4 | 0 | 5 |
| 10 | 34 | 33 | 0.04 | 12.7 | 12.9 | 9 | 20.5 | 6.5 | 1.0 | + | 26 030 | 15 200 | 0 | 14.3 | 8.4 | 0.00 | 12 | 0 | 5 | 0 | 5 |
| 11 | 41 | 34 | 0.22 | 14.7 | 14.5 | 10 | 20.3 | 7.0 | 0.7 | + | 31 510 | 17 200 | 0 | 15.0 | 8.2 | 0.00 | 10 | 0 | 5 | 0 | 8 |
| 12 | 18 | 33 | 0.17 | 15.9 | 15.4 | 10 | 19.7 | 5.8 | 0.9 | + | 30 134 | 15 900 | 0 | 13.3 | 7.0 | 0.00 | 13 | 0 | 5 | 0 | 7 |
| 13 | 14 | 32 | 0.30 | 18.5 | 16.0 | 10 | 23.3 | 3.8 | 0.7 | + | 41 552 | 16 980 | 0 | 15.7 | 6.4 | 0.00 | 15 | 0 | 5 | 0 | 6 |
| 14 | 31 | 28 | tr. | 17.2 | 15.6 | 10 | 20.2 | 3.9 | 1.9 | + | 38 220 | 14 520 | 0 | 15.5 | 5.9 | 0.00 | 10 | 0 | 8 | 0 | 6 |
| 15 | 32 | 26 | tr. | 13.9 | 14.4 | 9 | 20.4 | 4.4 | 0.7 | + | 30 576 | 11 460 | 0 | 15.4 | 5.8 | 0.00 | 7 | 0 | 13 | 0 | 4 |
| 16 | 29 | 33 | 0.32 | 15.9 | 14.6 | 10 | 18.9 | 4.4 | 1.2 | + | 34 754 | 19 560 | 0 | 15.3 | 8.6 | 0.00 | 10 | 0 | 7 | 0 | 4 |
| 17 | 26 | 31 | tr. | 14.6 | 13.0 | 10 | 19.0 | 2.3 | 1.1 | + | 32 544 | 18 540 | 0 | 15.6 | 8.9 | 0.00 | 13 | 0 | 5 | 0 | 6 |
| 18 | 25 | 32 | tr. | 14.5 | 15.0 | 10 | 18.1 | 4.0 | 1.1 | + | 32 296 | 17 460 | 0 | 15.6 | 8.4 | 0.00 | 10 | 0 | 5 | 0 | 4 |
| 19 | 27 | 32 | 0.00 | 16.0 | 14.4 | 10 | 20.7 | 3.0 | 2.4 | + | 35 266 | 18 660 | 0 | 15.4 | 8.2 | 0.00 | 10 | 0 | 5 | 0 | 4 |
| 20 | 32 | 33 | 0.00 | 14.9 | 14.0 | 10 | 18.6 | 2.6 | 0.6 | + | 32 487 | 17 880 | 0 | 15.2 | 8.4 | 0.00 | 10 | 0 | 5 | 0 | 6 |
| 21 | 35 | 32 | 0.00 | 14.9 | 14.6 | 10 | 19.2 | 8.0 | 3.9 | + | 31 825 | 17 820 | 0 | 14.9 | 8.4 | 0.00 | 13 | 0 | 6 | 0 | 4 |
| 22 | 45 | 33 | 0.12 | 14.9 | 14.4 | 10 | 18.8 | 8.0 | 3.9 | + | 31 819 | 18 180 | 0 | 14.9 | 8.5 | 0.00 | 12 | 0 | 5 | 0 | 5 |
| 23 | 52 | 35 | 0.28 | 14.9 | 14.5 | 10 | 18.8 | 8.0 | 4.5 | + | 31 161 | 17 940 | 0 | 14.6 | 8.4 | 0.00 | 13 | 0 | 8 | 0 | 4 |
| 24 | 57 | 41 | 0.00 | 12.9 | 12.4 | 10 | 16.6 | 8.0 | 6.0 | + | 27 274 | 16 320 | 0 | 14.8 | 8.8 | 0.00 | 20 | 0 | 8 | 0 | 5 |
| 25 | 45 | 43 | 0.00 | 14.8 | 14.6 | 9 | 20.6 | 8.0 | 4.7 | + | 31 632 | 18 660 | 0 | 14.9 | 8.8 | 0.00 | 13 | 0 | 18 | 0 | 4 |
| 26 | 37 | 40 | 0.00 | 14.6 | 14.0 | 9 | 20.3 | 8.0 | 4.3 | + | 30 709 | 17 880 | 0 | 14.7 | 8.6 | 0.00 | 15 | 0 | 10 | 0 | 5 |
| 27 | 37 | 38 | 0.00 | 14.1 | 13.8 | 9 | 19.7 | 8.0 | 6.0 | + | 30 527 | 17 160 | 0 | 15.1 | 8.5 | 0.00 | 15 | 0 | 10 | 0 | 4 |
| 28 | 30 | 36 | 0.04 | 14.2 | 13.5 | 9 | 19.6 | 8.0 | 3.8 | + | 28 350 | 15 000 | 0 | 14.0 | 7.4 | 0.00 | 15 | 0 | 10 | 0 | 4 |
| 29 | 34 | 36 | 0.39 | 14.3 | 14.0 | 9 | 19.0 | 8.0 | 4.3 | + | 23 950 | 14 840 | 0 | 14.7 | 7.3 | 0.00 | 20 | 0 | 10 | 0 | 3 |
| 30 | 22 | 33 | 0.21 | 15.8 | 15.0 | 9 | 20.8 | 8.0 | 4.1 | + | 32 850 | 19 260 | 0 | 14.5 | 8.5 | 0.00 | 15 | 0 | 12 | 0 | 3 |
| 31 | 14 | 32 | tr. | 16.1 | 14.5 | 9 | 21.9 | 7.9 | 4.3 | + | 34 200 | 20 220 | 0 | 14.9 | 8.8 | 0.00 | 15 | 0 | 12 | 0 | 4 |
| Av. | 32 | 34 | .... | 15.0 | 14.3 | 10 | 19.6 | 5.7 | 2.4 | .... | 31 164 | 16 795 | 105 | 14.6 | 7.8 | 0.05 | 16 | 0.4 | 7 | 0 | 5 |

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for January, 1909.

| Analytical Results, in Parts per Million. | | | | | | | | | | | | | | | | | | | Bacteriological Tests. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total hardness. | | | | Total alkalinity. | | | Caustic alk. | | | | Incrustants. | | | | Magnesium. | | Bacteria per c. c. | | | Presumptive *Coli* tests. | | | | | |
| | | | | | | | | | | | | | | | | | | | | River water. | | | Filtered water. | | |
| | | | | | | | | | | | | | | | | | | | | 1 c. c. | | | 1 c. c. | | 50 c.c. |
| River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Inlet to sett. basin | Settled water. | Filtered water. | Inlet to sett. basin. | Settled water. | Filtered water. | Mono. carb. alk., filtered water. | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Filtered water. | River water. | Settled water. | Filtered water. | Smith method. | Bile method. | Smith method. | Bile method. | Smith method. |
| 417 | 135 | 132 | 110 | 232 | 73 | 63 | 50 | 0 | 1 | 7 | 43 | 185 | 62 | 69 | 59 | 45 | 16 | 75 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 429 | 120 | 126 | 120 | 237 | 51 | 59 | 52 | 3 | 1 | 8 | 44 | 192 | 69 | 67 | 67 | 42 | 14 | 75 | 3 | 1 | 0 | 0 | 0 | 0 | 0 |
| 423 | 149 | 132 | 120 | 237 | 71 | 59 | 50 | 0 | 1 | 9 | 41 | 186 | 78 | 73 | 70 | 37 | 10 | 75 | 1 | 2 | + | 0 | 0 | 0 | 0 |
| 425 | 143 | 140 | 124 | 235 | 69 | 65 | 53 | 0 | 0 | 5 | 48 | 190 | 74 | 75 | 71 | 43 | 12 | 50 | 3 | 1 | 0 | 0 | 0 | 0 | 0 |
| 399 | 116 | 127 | 119 | 221 | 57 | 62 | 53 | 7 | 2 | 3 | 50 | 178 | 59 | 65 | 66 | 38 | 13 | 60 | 5 | 1 | 0 | 0 | 0 | 0 | 0 |
| 394 | 120 | 111 | 106 | 221 | 42 | 41 | 49 | 6 | 0 | 5 | 44 | 173 | 78 | 68 | 57 | 40 | 11 | 150 | 4 | 3 | 0 | 0 | 0 | 0 | 0 |
| 406 | 124 | 119 | 101 | 227 | 55 | 36 | 32 | 0 | 0 | 2 | 30 | 178 | 69 | 83 | 69 | 34 | 19 | 175 | 4 | 2 | 0 | 0 | 0 | 0 | 0 |
| 417 | 142 | 120 | 104 | 237 | 71 | 41 | 29 | 0 | 0 | 5 | 24 | 180 | 71 | 78 | 75 | 43 | 8 | 250 | 5 | 2 | 0 | 0 | 0 | 0 | 0 |
| 430 | 147 | 141 | 113 | 242 | 71 | 63 | 39 | 0 | 0 | 1 | 38 | 188 | 76 | 78 | 74 | 41 | 10 | 275 | 4 | 3 | 0 | 0 | 0 | 0 | 0 |
| 425 | 141 | 148 | 130 | 230 | 66 | 71 | 50 | 0 | 0 | 0 | 48 | 186 | 76 | 76 | 80 | 45 | 18 | 450 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 408 | 129 | 130 | 128 | 228 | 55 | 61 | 54 | 9 | 1 | 5 | 49 | 180 | 74 | 69 | 74 | 39 | 30 | 600 | 2 | 3 | 0 | 0 | 0 | 0 | 0 |
| 406 | 122 | 116 | 107 | 229 | 60 | 55 | 48 | 6 | 5 | 7 | 41 | 177 | 62 | 61 | 59 | 44 | 17 | 150 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 416 | 129 | 114 | 106 | 235 | 50 | 54 | 48 | 18 | 10 | 18 | 30 | 181 | 79 | 60 | 57 | 42 | 12 | 225 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 419 | 131 | 125 | 121 | 238 | 55 | 48 | 44 | 1 | 12 | 25 | 19 | 181 | 76 | 77 | 77 | 45 | 10 | 175 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 416 | 132 | 159 | 122 | 236 | 46 | 41 | 39 | 2 | 9 | 20 | 19 | 180 | 86 | 118 | 83 | 50 | 9 | — | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 414 | 121 | 141 | 123 | 235 | 46 | 44 | 37 | 10 | 10 | 16 | 21 | 179 | 74 | 97 | 86 | 43 | 11 | 25 | 2 | 2 | 0 | 0 | 0 | 0 | 0 |
| 406 | 99 | 106 | 110 | 232 | 48 | 49 | 41 | 18 | 11 | 20 | 21 | 174 | 50 | 57 | 69 | 43 | 11 | 135 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 414 | 110 | 105 | 100 | 237 | 51 | 52 | 47 | 15 | 16 | 21 | 26 | 177 | 59 | 54 | 53 | 43 | 10 | 200 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 428 | 121 | 109 | 97 | 242 | 46 | 50 | 47 | 16 | 14 | 26 | 21 | 186 | 75 | 59 | 49 | 44 | 10 | 220 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 431 | 120 | 122 | 105 | 244 | 58 | 55 | 46 | 22 | 13 | 22 | 24 | 187 | 62 | 67 | 59 | 43 | 10 | 160 | 0 | 0 | + | 0 | 0 | 0 | 0 |
| 425 | 100 | 136 | 116 | 241 | 62 | 69 | 45 | 36 | 0 | 9 | 36 | 184 | 38 | 67 | 71 | 45 | 11 | 120 | 10 | 2 | 0 | 0 | 0 | 0 | 0 |
| 401 | 100 | 121 | 108 | 225 | 66 | 59 | 39 | 38 | 15 | 7 | 32 | 176 | 34 | 61 | 69 | 43 | 11 | 50 | 7 | 7 | 0 | 0 | 0 | 0 | 0 |
| 394 | 93 | 129 | 94 | 219 | 64 | 60 | 39 | 34 | 2 | 12 | 27 | 175 | 29 | 60 | 55 | 42 | 11 | 150 | 40 | 6 | 0 | 0 | 0 | 0 | 0 |
| 395 | 116 | 117 | 89 | 219 | 92 | 66 | 35 | 64 | 10 | 14 | 21 | 176 | 23 | 51 | 54 | 37 | 6 | 3 900 | 44 | 10 | + | 0 | 0 | 0 | 0 |
| 411 | 96 | 116 | 91 | 227 | 65 | 69 | 47 | 41 | 19 | 27 | 20 | 184 | 31 | 47 | 44 | 37 | 7 | 2 500 | 30 | 30 | 0 | + | 0 | 0 | 0 |
| 434 | 113 | 117 | 93 | 238 | 51 | 62 | 44 | 27 | 2 | 20 | 21 | 196 | 62 | 55 | 49 | 45 | 11 | 400 | 40 | 6 | 0 | 0 | 0 | 0 | 0 |
| 434 | 110 | 126 | 96 | 236 | 65 | 59 | 34 | 33 | 0 | 8 | 26 | 189 | 45 | 68 | 62 | 45 | 9 | 550 | 60 | 10 | 0 | 0 | 0 | 0 | 0 |
| 426 | 115 | 122 | 93 | 237 | 56 | 56 | 31 | 26 | 4 | 6 | 25 | 189 | 59 | 66 | 62 | 45 | 12 | 425 | — | 4 | 0 | 0 | 0 | 0 | 0 |
| 425 | 123 | 117 | 111 | 235 | 58 | 47 | 30 | 16 | 0 | 8 | 22 | 190 | 64 | 71 | 80 | 45 | 13 | 425 | — | 4 | 0 | 0 | 0 | 0 | 0 |
| 441 | 130 | 141 | 107 | 241 | 66 | 61 | 32 | 36 | 0 | 3 | 29 | 200 | 64 | 79 | 75 | 46 | 10 | 500 | 45 | 12 | 0 | 0 | 0 | 0 | 0 |
| 437 | 114 | 129 | 105 | 238 | 62 | 64 | 36 | 20 | 2 | 5 | 31 | 199 | 52 | 65 | 69 | 44 | 16 | 500 | 12 | 4 | 0 | 0 | 0 | 0 | 0 |
| 417 | 121 | 125 | 109 | 233 | 60 | 56 | 43 | 16 | 5 | 11 | 31 | 184 | 61 | 69 | 66 | 42 | 12 | 435 | 11 | 3 | .... | .... | .... | .... | ..... |

Coaguiant = Sulphate of iron or sulphate of alumina.

TABLE 12.—WATER PURIFICATION WORKS.—(*Continued.*)

| Day of Month. | Temperature of air, in degrees Fahr. | Temperature of water, in degrees Fahr. | Rainfall, in inches. | Volume of Water. | | Filter Data. | | | | | Applied Chemicals. | | | | | | Color. | | Turbidity. | | Free carbonic acid, river water. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Pumped, million gal. | Filtered, million gal. | Number used. | Hours in service, average. | Loss of head, maximum, in feet. | Wash-water, percentage. | Use of air. | Pounds. | | | Grains per gallon. | | | River water. | Filtered water. | River water. | Filtered Water. | |
| | | | | | | | | | | | Lime. | Soda ash. | Coagulant. | Lime. | Soda ash. | Coagulant. | | | | | |
| 1 | 28 | 32 | 0.00 | 16.4 | 15.6 | 10 | 20.5 | 8.0 | 3.0 | 0 | 35 000 | 21 480 | 0 | 14.9 | 9.2 | 0 | 12 | 0 | 12 | 0 | 3 |
| 2 | 22 | 32 | 0.00 | 15.7 | 15.5 | 10 | 20.0 | 8.0 | 3.4 | 0 | 35 950 | 22 260 | 0 | 16.0 | 9.9 | 0 | 32 | 0 | 15 | 0 | 5 |
| 3 | 28 | 32 | 0.00 | 15.3 | 14.4 | 10 | 18.1 | 8.0 | 4.9 | 0 | 34 800 | 22 638 | 0 | 15.9 | 10.3 | 0 | 40 | 0 | 15 | 0 | 5 |
| 4 | 41 | 34 | 0.00 | 14.6 | 14.3 | 10 | 18.3 | 8.0 | 5.5 | 0 | 30 265 | 21 384 | 0 | 15.1 | 10.2 | 0 | 45 | 0 | 15 | 0 | 4 |
| 5 | 47 | 35 | 0.31 | 14.6 | 14.2 | 10 | 16.9 | 8.0 | 5.8 | 0 | 24 315 | 19 038 | 0 | 11.6 | 9.1 | 0 | 50 | 0 | 15 | 0 | 6 |
| 6 | 41 | 39 | 0.08 | 14.7 | 13.9 | 10 | 17.8 | 8.0 | 6.1 | 0 | 22 608 | 16 020 | 0 | 10.7 | 7.6 | 0 | 50 | 0 | 20 | 0 | 5 |
| 7 | 34 | 38 | 0.00 | 12.9 | 12.3 | 10 | 16.0 | 8.0 | 4.3 | 0 | 18 848 | 14 940 | 0 | 10.2 | 8.1 | 0 | 55 | 2 | 15 | 0 | 3 |
| 8 | 33 | 36 | 0.00 | 14.2 | 14.0 | 10 | 17.4 | 8.0 | 5.0 | 0 | 21 440 | 16 380 | 0 | 10.6 | 8.1 | 0 | — | 0 | — | 0 | 3 |
| 9 | 39 | 38 | 0.40 | 16.7 | 13.7 | 10 | 20.1 | 8.0 | 4.2 | 0 | 26 336 | 19 380 | 0 | 11.0 | 8.1 | 0 | 18 | 0 | 30 | 0 | 3 |
| 10 | 28 | 38 | tr. | 14.8 | 14.1 | 10 | 17.9 | 7.6 | 6.1 | 0 | 25 888 | 19 820 | 0 | 12.2 | 9.4 | 0 | 18 | 1 | 22 | 0 | 3 |
| 11 | 26 | 34 | 0.00 | 14.9 | 14.2 | 10 | 19.3 | 8.0 | 1.2 | 0 | 27 840 | 21 780 | 0 | 13.1 | 10.2 | 0 | 19 | 0 | 20 | 0 | 4 |
| 12 | 32 | 37 | 0.54 | 15.8 | 13.9 | 10 | 17.8 | 8.0 | 6.1 | 0 | 30 561 | 23 520 | 0 | 13.5 | 10.4 | 0 | 17 | 3 | 20 | 0 | 4 |
| 13 | 44 | 39 | 0.01 | 14.6 | 13.5 | 10 | 16.9 | 7.5 | 3.3 | 0 | 29 899 | 21 660 | 0 | 14.3 | 10.4 | 0 | 17 | 0 | 22 | 0 | 5 |
| 14 | 45 | 39 | 0.56 | 13.2 | 12.3 | 10 | 15.4 | 7.9 | 5.2 | 0 | 24 056 | 21 680 | 72 | 12.8 | 11.5 | 0.1 | 30 | 0 | 48 | 0 | 4 |
| 15 | 33 | 37 | 0.42 | 12.6 | 15.3 | 10 | 15.0 | 10.0 | 14.2 | 0 | 15 744 | 21 190 | 1 242 | 8.7 | 11.8 | 0.7 | 40 | 1 | 96 | 0 | 4 |
| 16 | 26 | 37 | 0.24 | 16.1 | 14.5 | 10 | 20.1 | 8.0 | 5.8 | 0 | 11 100 | 13 650 | 2 311 | 4.8 | 5.9 | 1.0 | 65 | 3 | 255 | 1 | 2 |
| 17 | 22 | 25 | 0.00 | 14.4 | 14.2 | 10 | 21.5 | 6.7 | 3.3 | 0 | 3 620 | 8 880 | 3 177 | 1.8 | 4.3 | 1.6 | 70 | 8 | 431 | 3 | 3 |
| 18 | 33 | 35 | 0.00 | 14.5 | 14.4 | 10 | 22.0 | 6.6 | 8.2 | 0 | 14 680 | 7 150 | 11 640 | 7.1 | 3.4 | 5.6 | 60 | 30 | 332 | 4 | 3 |
| 19 | 39 | 35 | 0.21 | 15.8 | 13.3 | 10 | 19.0 | 6.8 | 4.4 | 0 | 16 060 | 7 230 | 10 122 | 7.1 | 3.2 | 4.5 | 100 | 20 | 184 | 2 | 3 |
| 20 | 38 | 35 | 0.00 | 13.6 | 13.7 | 10 | 15.6 | 7.0 | 5.6 | 0 | 11 640 | 7 785 | 7 638 | 6.0 | 4.0 | 3.9 | 90 | 13 | 184 | 0 | 3 |
| 21 | 37 | 36 | tr. | 12.5 | 11.5 | 10 | 14.5 | 3.5 | 3.5 | 0 | 10 780 | 5 190 | 5 700 | 6.0 | 2.9 | 3.2 | 75 | 10 | 252 | 0 | 3 |
| 22 | 38 | 37 | 0.00 | 13.6 | 13.5 | 10 | 16.7 | 4.7 | 5.6 | 0 | 9 520 | 7 205 | 5 280 | 4.9 | 3.7 | 2.2 | 75 | 10 | 214 | 0 | 3 |
| 23 | 50 | 40 | 2.05 | 13.8 | 13.4 | 10 | 16.6 | 6.9 | 4.8 | 0 | 7 800 | 6 825 | 8 155 | 3.9 | 3.5 | 4.1 | 75 | 8 | 482 | 0 | 3 |
| 24 | 48 | 48 | 0.14 | 14.5 | 13.5 | 10 | 22.5 | 3.0 | 6.0 | 0 | 9 330 | 5 285 | 8 978 | 4.5 | 2.5 | 4.3 | 100 | 13 | 1 311 | 0 | 2 |
| 25 | 25 | 45 | tr. | 14.1 | 13.1 | 10 | 23.5 | 3.8 | 1.5 | 0 | 10 520 | 1 890 | 13 269 | 5.2 | 2.4 | 6.6 | — | 17 | 1 220 | 5 | 3 |
| 26 | 33 | 40 | 0.00 | 16.2 | 16.3 | 10 | 21.3 | 7.0 | 7.1 | 0 | 14 900 | 0 | 13 137 | 6.4 | 0 | 5.7 | 70 | 25 | 867 | 0 | 3 |
| 27 | 37 | 38 | tr. | 17.8 | 17.1 | 10 | 20.4 | 6.7 | 9.0 | 0 | 14 155 | 3 160 | 9 523 | 5.6 | 1.8 | 3.7 | 100 | — | 545 | 0 | 2 |
| 28 | 32 | 38 | 0.01 | 16.9 | 14.4 | 10 | 18.6 | 6.5 | 8.0 | 0 | 7 567 | 4 120 | 10 500 | 3.1 | 1.7 | 4.3 | 80 | 15 | 302 | 0 | 2 |
| Av. | 35 | 37 | .... | 14.8 | 14.1 | 10 | 18.6 | 7.1 | 5.4 | .. | 19 472 | 13 626 | 3 955 | 9.1 | 6.6 | 1.8 | 54 | 7 | 256 | 0.5 | 3 |

\+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for February, 1909.

| Analytical Results, in Parts per Million. | | | | | | | | | | | | | | | | | | | | | | Bacteriological Tests. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total hardness. | | | | Total alkalinity. | | | | Caustic alk. | | | Mono. carb. alk., filtered water. | Incrustants. | | | | Magnesium. | | Bacteria per c. c. | | | Presumptive *Coli* tests. | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | River water. | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | 1 c. c. | | | 1 c. c. | | 50 c.c. | |
| River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | Inlet to sett. basin. | Settled water. | Filtered water. | | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Filtered water. | River water. | Settled water. | Filtered water. | Smith method. | Bile method. | Smith method. | Bile method. | Smith method. | | |
| 450 | 119 | 140 | 107 | 245 | 62 | 69 | 37 | 26 | 0 | 6 | 31 | 205 | 57 | 71 | 70 | 45 | 13 | 400 | 9 | 2 | 0 | 0 | 0 | 0 | 0 | | |
| 447 | 111 | 142 | 102 | 243 | 62 | 70 | 33 | 30 | 0 | 3 | 30 | 204 | 49 | 72 | 69 | 48 | 11 | 375 | 7 | 2 | 0 | 0 | 0 | 0 | 0 | | |
| 427 | 108 | 136 | 96 | 232 | 88 | 77 | 37 | 62 | 9 | 10 | 27 | 195 | 20 | 59 | 59 | 46 | 11 | 200 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | | |
| 416 | 121 | 135 | 92 | 223 | 97 | 85 | 47 | 63 | 21 | 22 | 25 | 193 | 24 | 50 | 46 | 40 | 7 | 400 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | | |
| 405 | 122 | 137 | 96 | 220 | 90 | 86 | 52 | 20 | 12 | 27 | 25 | 185 | 32 | 51 | 44 | 42 | 15 | 300 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | | |
| 405 | 120 | 140 | 108 | 220 | 63 | 81 | 54 | 13 | 0 | 9 | 45 | 185 | 57 | 59 | 54 | 32 | 4 | 725 | 15 | 2 | 0 | 0 | 0 | 0 | 0 | | |
| 416 | 142 | 143 | 107 | 223 | 83 | 79 | 48 | 11 | 0 | 2 | 46 | 193 | 59 | 64 | 59 | 34 | 13 | — | — | — | 0 | 0 | 0 | 0 | 0 | | |
| 419 | 145 | 163 | 132 | 225 | 90 | 84 | 58 | 2 | 0 | 0 | 46 | 194 | 55 | 79 | 74 | 43 | 23 | 450 | 5 | 5 | 0 | 0 | 0 | 0 | + | | |
| 419 | 142 | 168 | 142 | 224 | 78 | 91 | 67 | 4 | 0 | 0 | 50 | 195 | 65 | 77 | 75 | 40 | 21 | 725 | 20 | 13 | 0 | 0 | 0 | 0 | 0 | | |
| 405 | 104 | 164 | 133 | 219 | 69 | 83 | 61 | 17 | 0 | 0 | 44 | 186 | 35 | 81 | 72 | 40 | 23 | 2 000 | 120 | 22 | + | 0 | 0 | 0 | + | | |
| 421 | 110 | 138 | 116 | 223 | 64 | 74 | 52 | 16 | 4 | 1 | 51 | 198 | 47 | 64 | 64 | 38 | 15 | 600 | — | 10 | + | 0 | 0 | 0 | 0 | | |
| 419 | 103 | 136 | 102 | 218 | 79 | 78 | 51 | 35 | 0 | 5 | 46 | 201 | 24 | 58 | 51 | 38 | 10 | 400 | 15 | 8 | 0 | 0 | 0 | 0 | — | | |
| 409 | 115 | 122 | 99 | 209 | 72 | 74 | 47 | 62 | 0 | 4 | 43 | 200 | 43 | 48 | 52 | 40 | 17 | 1 200 | 10 | 6 | 0 | 0 | 0 | 0 | 0 | | |
| 389 | 113 | 123 | 94 | 180 | 95 | 66 | 47 | 67 | 12 | 15 | 32 | 209 | 18 | 57 | 47 | 38 | 8 | 17 500 | 400 | 15 | + | + | 0 | 0 | 0 | | |
| 356 | 110 | 118 | 100 | 150 | 84 | 79 | 51 | 24 | 31 | 26 | 25 | 206 | 25 | 39 | 49 | 25 | 6 | 16 000 | 50 | 6 | + | + | 0 | 0 | 0 | | |
| 220 | 128 | 110 | 87 | 92 | 84 | 65 | 55 | 32 | 9 | 27 | 28 | 128 | 44 | 45 | 32 | 15 | 4 | 50 000 | 250 | 80 | + | + | 0 | 0 | 0 | | |
| 167 | 154 | 104 | 77 | 75 | 124 | 63 | 40 | 0 | 0 | 7 | 33 | 92 | 30 | 41 | 37 | 14 | 6 | 100 000 | 50 000 | 500 | + | + | 0 | 0 | 0 | | |
| 195 | 178 | 128 | 103 | 83 | 120 | 74 | 58 | 44 | 0 | 0 | 26 | 112 | 53 | 54 | 45 | 13 | 5 | 60 000 | 1 000 | 800 | + | + | + | 0 | + | | |
| 206 | 182 | 132 | 116 | 85 | 103 | 43 | 48 | 67 | 0 | 0 | 10 | 121 | 79 | 88 | 68 | 18 | — | 80 000 | 100 | 150 | + | + | 0 | 0 | 0 | | |
| 186 | 158 | 144 | 123 | 81 | 84 | 44 | 42 | 22 | 0 | 0 | 18 | 105 | 74 | 100 | 81 | 23 | 8 | 80 000 | 110 | 22 | + | + | 0 | 0 | 0 | | |
| 147 | 167 | 125 | 127 | 68 | 124 | 44 | 40 | 38 | 0 | 0 | 16 | 79 | 42 | 81 | 87 | 17 | 8 | 75 000 | 80 | 7 | + | + | 0 | 0 | 0 | | |
| 142 | 152 | 134 | 110 | 66 | 130 | 85 | 45 | 32 | 0 | 0 | 28 | 76 | 22 | 49 | 65 | 10 | 8 | 75 000 | 95 | 8 | + | + | 0 | 0 | 0 | | |
| 140 | 142 | 114 | 96 | 69 | 114 | 84 | 56 | 2 | 0 | 1 | 55 | 71 | 28 | 30 | 40 | 9 | 8 | 73 000 | 350 | 25 | + | + | 0 | 0 | 0 | | |
| 94 | 142 | 106 | 97 | 56 | 136 | 66 | 52 | 28 | 0 | 0 | 30 | 38 | 6 | 40 | 45 | 9 | 6 | 100 000 | 450 | 100 | 0 | + | 0 | 0 | + | | |
| 72 | 147 | 97 | 89 | 54 | 127 | 74 | 62 | 33 | 0 | 0 | 18 | 18 | 20 | 23 | 27 | 10 | 7 | 55 000 | 1 200 | 285 | + | + | 0 | 0 | + | | |
| 85 | 179 | 98 | 88 | 56 | 143 | 54 | 54 | 54 | 0 | 0 | 20 | 29 | 37 | 44 | 33 | 6 | 2 | 14 000 | 145 | 40 | 0 | 0 | 0 | 0 | 0 | | |
| 93 | 186 | 151 | 101 | 59 | 150 | 101 | 60 | 54 | 17 | 22 | 38 | 34 | 36 | 49 | 41 | 9 | 3 | 53 000 | 250 | 32 | + | + | 0 | 0 | 0 | | |
| 117 | 149 | 126 | 105 | 68 | 120 | 87 | 62 | 8 | 17 | 37 | 25 | 49 | 29 | 39 | 43 | 15 | 4 | 30 000 | 1 100 | 70 | + | + | 0 | 0 | 0 | | |
| 288 | 137 | 131 | 105 | 149 | 98 | 74 | 51 | 31 | 5 | 8 | 32 | 139 | 40 | 58 | 55 | 27 | 10 | 32 825 | 2 146 | 82 | .... | .... | .... | .... | ..... | | |

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12.—WATER PURIFICATION WORKS—(*Continued.*)

| Day of Month. | Temperature of air, in degrees Fahr. | Temperature of water, in degrees Fahr. | Rainfall, in inches. | Volume of Water. | | Filter Data. | | | | | Applied Chemicals. | | | | | | Color. | | Turbidity. | | | | Free carbonic acid, river water. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Pounds. | | | Grains per gallon. | | | | | | | | | |
| | | | | Pumped, million gal. | Filtered, million gal. | Number used. | Hours in service, average. | Loss of head, maximum, in feet. | Wash-water, percentage. | Use of air. | Lime. | Soda ash. | Coagulant. | Lime. | Soda ash. | Coagulant. | River water. | Filtered water. | River water. | Settled water. | Filtered water. | Filtered water. | |
| 1 | 37 | 42 | 0.35 | 15.2 | 15.6 | 10 | 18.7 | 6.3 | 5.6 | 0 | 5 888 | 3 372 | 10 614 | 2.7 | 1.6 | 4.9 | 80 | 20 | 188 | 25 | 0 | 0 | + |
| 2 | 45 | 41 | 0.14 | 16.2 | 14.8 | 10 | 17.7 | 6.0 | 5.1 | 0 | 9 419 | 8 595 | 8 936 | 4.1 | 3.7 | 3.9 | 75 | 30 | 135 | 35 | 0 | 0 | + |
| 3 | 40 | 40 | 0.22 | 16.0 | 14.7 | 10 | 19.1 | 4.8 | 6.8 | 0 | 12 440 | 14 873 | 6 345 | 5.4 | 6.5 | 2.8 | 75 | 30 | 100 | 20 | 0 | 0 | + |
| 4 | 29 | 41 | 0.00 | 14.8 | 14.8 | 10 | 16.9 | 4.0 | 5.9 | 0 | 10 912 | 15 430 | 5 022 | 5.2 | 7.3 | 2.4 | 65 | 35 | 90 | 20 | 1 | 3 | + |
| 5 | 30 | 40 | 0.00 | 16.4 | 14.5 | 10 | 18.1 | 4.9 | 4.5 | 0 | 17 916 | 17 025 | 3 810 | 7.6 | 7.3 | 1.6 | 65 | 25 | 93 | 20 | 0 | 3 | + |
| 6 | 40 | 42 | 0.01 | 16.6 | 13.8 | 10 | 15.8 | 6.0 | 6.0 | 0 | 19 425 | 17 250 | 3 454 | 8.2 | 7.3 | 1.5 | 65 | 20 | 92 | 20 | 0 | 4 | + |
| 7 | 41 | 42 | 0.00 | 12.9 | 11.4 | 10 | 14.5 | 3.7 | 5.3 | 0 | 14 275 | 12 525 | 2 716 | 7.7 | 6.8 | 1.5 | 50 | 12 | 71 | 20 | 0 | 4 | + |
| 8 | 39 | 40 | 0.03 | 15.2 | 13.2 | 10 | 15.9 | 5.0 | 4.5 | 0 | 15 750 | 16 275 | 2 603 | 7.2 | 7.5 | 1.2 | 45 | 0 | 52 | 20 | 0 | 3 | + |
| 9 | 49 | 42 | 0.98 | 15.5 | 12.7 | 10 | 16.9 | 3.3 | 5.2 | 0 | 14 975 | 15 900 | 1 660 | 6.8 | 7.2 | 0.7 | 60 | 0 | 78 | 20 | 0 | 2 | + |
| 10 | 48 | 46 | tr. | 13.4 | 12.6 | 10 | 17.8 | 4.7 | 5.0 | 0 | 9 530 | 9 062 | 7 952 | 5.0 | 4.7 | 4.0 | — | — | 210 | 20 | 0 | 2 | + |
| 11 | 39 | 44 | 0.00 | 14.3 | 12.9 | 10 | 20.5 | 4.0 | 6.9 | 0 | 8 560 | 5 228 | 11 178 | 4.2 | 2.6 | 5.5 | — | 5 | 479 | 20 | 0 | 3 | + |
| 12 | 36 | 43 | tr. | 13.7 | 12.8 | 10 | 20.5 | 3.2 | 6.6 | 0 | 7 664 | 4 235 | 8 148 | 3.9 | 2.2 | 4.2 | — | 10 | 373 | 20 | 0 | 2 | + |
| 13 | 42 | 43 | 0.00 | 12.4 | 13.1 | 10 | 21.6 | 2.8 | 7.2 | 0 | 9 296 | 4 979 | 6 592 | 5.2 | 2.8 | 3.7 | — | 10 | 352 | 30 | 3 | 4 | + |
| 14 | 35 | 42 | tr. | 13.8 | 11.2 | 10 | 20.8 | 3.0 | 8.1 | 0 | 10 960 | 7 865 | 7 763 | 5.6 | 4.0 | 4.0 | — | 30 | 197 | 30 | 3 | 3 | + |
| 15 | 34 | 41 | 0.00 | 14.3 | 13.0 | 10 | 17.9 | 3.4 | 6.7 | 0 | 11 712 | 7 595 | 6 884 | 5.7 | 3.7 | 3.4 | 70 | 12 | 120 | 20 | 3 | 5 | + |
| 16 | 32 | 41 | 0.03 | 13.6 | 12.7 | 10 | 16.9 | 2.7 | 6.1 | 0 | 13 680 | 10 545 | 4 894 | 7.0 | 5.4 | 2.5 | — | 18 | 91 | 0 | 3 | 5 | + |
| 17 | 29 | 39 | 0.00 | 13.7 | 13.0 | 10 | 18.0 | 3.6 | 6.8 | 0 | 14 037 | 13 325 | 2 864 | 7.2 | 6.8 | 1.5 | 55 | 15 | 72 | 0 | 0 | 3 | + |
| 18 | 33 | 41 | 0.01 | 13.4 | 12.7 | 10 | 14.3 | 9.7 | 6.9 | 0 | 13 446 | 12 950 | 1 850 | 7.0 | 6.7 | 1.0 | 52 | 3 | 56 | 5 | 0 | 4 | + |
| 19 | 46 | 43 | 0.07 | 13.9 | 12.7 | 10 | 15.9 | 4.0 | 4.6 | 0 | 14 202 | 12 040 | 1 875 | 7.1 | 6.1 | 0.9 | — | 2 | 47 | 10 | 0 | 4 | + |
| 20 | 40 | 42 | 0.00 | 14.2 | 13.4 | 10 | 16.5 | 3.6 | 3.8 | 0 | 13 824 | 14 700 | 1 995 | 6.8 | 7.2 | 1.0 | — | 0 | 37 | 15 | 0 | 4 | + |
| 21 | 36 | 41 | 0.00 | 11.5 | 10.8 | 10 | 17.6 | 3.7 | 5.3 | 0 | 11 799 | 11 895 | 1 605 | 7.2 | 7.2 | 1.0 | 70 | 0 | 35 | 15 | 0 | 4 | + |
| 22 | 34 | 40 | 0.00 | 14.2 | 13.1 | 10 | 19.0 | 2.8 | 6.8 | 0 | 16 518 | 16 725 | 1 785 | 8.1 | 8.2 | 0.9 | 55 | 5 | 26 | 15 | 0 | 3 | + |
| 23 | 45 | 45 | 0.00 | 13.9 | 12.4 | 10 | 17.7 | 2.8 | 3.9 | 0 | 15 912 | 17 360 | 1 659 | 8.0 | 8.7 | 0.8 | 70 | 0 | 25 | 15 | 0 | 4 | + |
| 24 | 44 | 43 | 0.65 | 12.7 | 12.3 | 10 | 16.5 | 3.3 | 3.8 | 0 | 14 752 | 15 680 | 1 004 | 8.1 | 8.6 | 0.6 | 70 | 0 | 25 | 15 | 0 | 4 | + |
| 25 | 36 | 41 | 0.18 | 13.1 | 12.3 | 10 | 17.2 | 2.9 | 4.7 | 0 | 14 554 | 14 700 | 1 237 | 7.7 | 7.8 | 0.7 | 70 | 0 | 25 | 15 | 0 | 3 | + |
| 26 | 34 | 42 | 0.00 | 13.5 | 12.3 | 9 | 19.4 | 2.6 | 2.7 | 0 | 14 950 | 13 650 | 1 312 | 7.7 | 7.1 | 0.7 | 80 | 0 | 27 | 15 | 0 | 5 | + |
| 27 | 44 | 44 | 0.00 | 13.3 | 12.5 | 9 | 19.7 | 5.9 | 3.6 | 0 | 14 924 | 14 560 | 1 258 | 7.7 | 7.7 | 0.7 | 80 | 3 | 30 | 15 | 0 | 5 | + |
| 28 | 48 | 46 | 0.00 | 11.8 | 10.8 | 10 | 18.4 | 4.1 | 3.3 | 0 | 11 544 | 13 020 | 1 043 | 6.8 | 7.7 | 0.6 | 85 | 0 | 47 | 15 | 0 | 3 | + |
| 29 | 43 | 43 | tr. | 14.3 | 12.9 | 10 | 19.5 | 3.7 | 3.1 | 0 | 13 858 | 14 397 | 1 320 | 6.8 | 7.0 | 0.6 | 85 | 0 | 68 | 15 | 0 | 3 | + |
| 30 | 39 | 42 | 0.01 | 13.4 | 12.1 | 10 | 18.0 | 3.6 | 2.5 | 0 | 11 778 | 11 574 | 1 515 | 6.1 | 6.0 | 0.8 | 85 | 0 | 80 | 15 | 0 | 4 | + |
| 31 | 39 | 43 | 0.00 | 13.5 | 12.1 | 10 | 16.8 | 4.3 | 3.2 | 0 | 10 020 | 8 649 | 2 670 | 5.2 | 4.5 | 1.4 | 85 | 0 | 78 | 15 | 0 | 3 | + |
| Av. | 39 | 42 | .... | 14.0 | 12.9 | 10 | 17.9 | 4.1 | 5.2 | .. | 12 855 | 12 128 | 3 985 | 6.4 | 6.1 | 2.0 | 56 | 9 | 109 | 17 | 0.4 | 3 | |

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for March, 1909.

| Analytical Results, in Parts per Million. | | | | | | | | | | | | | | | | | | | | | Bacteriological Tests. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total hardness. | | | | Total alkalinity. | | | | Caustic alk. | | | | Incrustants. | | | | Magnesium. | | | | | Bacteria per c.c. | | | Presumptive *Coli* tests. | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | River water. | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | 1 c.c. | | | 50 c.c. |
| River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | Inlet to sett. basin. | Settled water. | Filtered water. | Mono. carb. alk., filtered water. | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Filtered water. | | | | River water. | Settled water. | Filtered water. | Smith method. | Bile method. | Smith method. | Bile method. | Smith method. |
| 155 | 172 | 131 | 85 | 79 | 116 | 71 | 41 | 0 | 0 | 9 | 32 | 76 | 55 | 60 | 44 | 12 | 2 | | | | 32 500 | 17 000 | 275 | + | + | 0 | 0 | + |
| 187 | 175 | 155 | 119 | 86 | 137 | 88 | 49 | 0 | 0 | 0 | 24 | 101 | 37 | 67 | 71 | 12 | 6 | | | | 28 000 | 1 000 | 385 | + | 0 | + | 0 | + |
| 215 | 153 | 135 | 124 | 96 | 122 | 75 | 65 | 14 | 0 | 0 | 26 | 118 | 32 | 60 | 59 | 11 | 6 | | | | 18 000 | 300 | 330 | − | + | 0 | 0 | + |
| 231 | 131 | 105 | 99 | 103 | 107 | 65 | 58 | 11 | 0 | 0 | 40 | 128 | 24 | 41 | 41 | 15 | 8 | | | | 8 000 | 25 | 38 | 0 | 0 | 0 | 0 | 0 |
| 247 | 124 | 112 | 96 | 108 | 99 | 69 | 56 | 25 | 0 | 0 | 48 | 139 | 25 | 43 | 40 | 17 | 9 | | | | 36 000 | 400 | 300 | 0 | 0 | 0 | 0 | 0 |
| 246 | 124 | 80 | 80 | 114 | 99 | 52 | 49 | 41 | 6 | 0 | 30 | 131 | 25 | 28 | 31 | 17 | 12 | | | | 45 000 | 170 | 34 | 0 | 0 | 0 | 0 | 0 |
| 248 | 121 | 84 | 71 | 115 | 96 | 60 | 53 | 36 | 20 | 12 | 41 | 133 | 25 | 24 | 18 | 18 | 6 | | | | 8 000 | − | 1 | 0 | − | 0 | | 0 |
| 259 | 131 | 84 | 69 | 119 | 102 | 51 | 49 | 36 | 11 | 22 | 27 | 141 | 29 | 33 | 20 | 19 | 5 | | | | 9 350 | 12 | 2 | 0 | 0 | 0 | 0 | 0 |
| 259 | 134 | 77 | 61 | 123 | 106 | 51 | 41 | 16 | 3 | 16 | 25 | 136 | 27 | 26 | 20 | 19 | 4 | | | | 22 000 | 30 | 0 | 0 | 0 | 0 | 0 | 0 |
| 185 | 133 | 91 | 64 | 94 | 104 | 60 | 42 | 30 | 0 | 10 | 32 | 91 | 29 | 31 | 22 | 15 | 7 | | | | 60 000 | 70 | 2 | 0 | + | 0 | 0 | 0 |
| 144 | 131 | 112 | 76 | 76 | 111 | 69 | 41 | 13 | 0 | 2 | 39 | 68 | 30 | 43 | 35 | 10 | 6 | | | | 70 000 | 600 | 2 | + | + | 0 | 0 | + |
| 144 | 158 | 128 | 96 | 81 | 126 | 76 | 50 | 0 | 0 | 0 | 42 | 63 | 32 | 52 | 46 | 9 | 10 | | | | 125 000 | 2 500 | 300 | + | + | 0 | 0 | 0 |
| 139 | 143 | 114 | 97 | 83 | 126 | 72 | 52 | 8 | 0 | 0 | 16 | 56 | 17 | 42 | 45 | 12 | 10 | | | | 30 000 | 700 | 300 | + | + | 0 | 0 | |
| 170 | 146 | 107 | 98 | 93 | 124 | 74 | 55 | 24 | 0 | 0 | 18 | 77 | 22 | 33 | 43 | 11 | 8 | | | | 26 000 | 200 | 300 | + | + | 0 | 0 | + |
| 196 | 138 | 97 | 97 | 101 | 106 | 60 | 48 | 24 | 0 | 0 | 32 | 95 | 32 | 37 | 49 | 13 | 10 | | | | 7 500 | 95 | 155 | 0 | + | 0 | 0 | 0 |
| 221 | 136 | 110 | 96 | 109 | 101 | 57 | 52 | 27 | 0 | 0 | 36 | 112 | 35 | 53 | 44 | 15 | 10 | | | | 3 750 | 10 | 9 | 0 | + | 0 | 0 | 0 |
| 228 | 129 | 109 | 102 | 115 | 98 | 55 | 43 | 43 | 0 | 0 | 26 | 113 | 30 | 54 | 59 | 17 | 9 | | | | 2 000 | 0 | 0 | + | + | 0 | 0 | 0 |
| 244 | 107 | 67 | 84 | 123 | 96 | 48 | 46 | 22 | 4 | 0 | 36 | 121 | 11 | 19 | 38 | 17 | 8 | | | | 900 | − | 0 | 0 | + | 0 | 0 | 0 |
| 274 | 109 | 85 | 68 | 137 | 86 | 54 | 46 | 16 | 4 | 2 | 44 | 137 | 23 | 31 | 22 | 22 | 8 | | | | 1 000 | 4 | 0 | + | 0 | 0 | 0 | 0 |
| 276 | 117 | 88 | 64 | 136 | 95 | 49 | 41 | 17 | 3 | 3 | 38 | 140 | 22 | 39 | 24 | 21 | 7 | | | | 550 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 290 | 120 | 92 | 75 | 142 | 88 | 54 | 39 | 16 | 0 | 3 | 36 | 148 | 32 | 38 | 36 | 21 | 8 | | | | 700 | 2 | 1 | 0 | 0 | 0 | 0 | 0 |
| 304 | 111 | 86 | 63 | 149 | 94 | 59 | 42 | 14 | 0 | 3 | 39 | 155 | 17 | 27 | 22 | 21 | 8 | | | | 400 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 311 | 110 | 82 | 68 | 157 | 92 | 55 | 43 | 12 | 0 | 5 | 38 | 155 | 18 | 27 | 25 | 24 | 7 | | | | 150 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 324 | 112 | 88 | 67 | 163 | 86 | 62 | 44 | 16 | 6 | 6 | 38 | 161 | 26 | 26 | 23 | 22 | 8 | | | | 140 | 3 | 1 | + | 0 | 0 | 0 | 0 |
| 319 | 119 | 94 | 67 | 163 | 82 | 69 | 51 | 0 | 0 | 5 | 46 | 156 | 37 | 25 | 16 | 22 | 6 | | | | 750 | 0 | 2 | 0 | + | 0 | 0 | 0 |
| 323 | 132 | 97 | 71 | 162 | 72 | 61 | 52 | 4 | 0 | 4 | 48 | 161 | 60 | 35 | 19 | 20 | 9 | | | | 700 | 6 | 0 | 0 | + | 0 | 0 | 0 |
| 322 | 114 | 106 | 82 | 159 | 70 | 52 | 46 | 12 | 0 | 3 | 43 | 163 | 44 | 54 | 36 | 24 | 10 | | | | 4 000 | 2 | 0 | + | 0 | 0 | 0 | 0 |
| 270 | 101 | 110 | 91 | 147 | 85 | 53 | 42 | 11 | 0 | 0 | 40 | 123 | 16 | 57 | 49 | 25 | 8 | | | | — | — | — | + | 0 | 0 | 0 | 0 |
| 268 | 107 | 84 | 84 | 130 | 80 | 61 | 42 | 16 | 0 | 4 | 38 | 138 | 27 | 23 | 42 | 19 | 7 | | | | 1 250 | 45 | 0 | 0 | 0 | 0 | 0 | 0 |
| 247 | 105 | 84 | 71 | 118 | 76 | 58 | 50 | 16 | 4 | 5 | 45 | 129 | 29 | 25 | 21 | 19 | 10 | | | | 2 500 | 15 | 0 | + | + | 0 | 0 | 0 |
| 224 | 113 | 82 | 66 | 115 | 72 | 49 | 45 | 4 | 0 | 5 | 40 | 109 | 41 | 33 | 21 | 19 | 10 | | | | 2 700 | 12 | 1 | + | 0 | 0 | 0 | 0 |
| 241 | 128 | 99 | 82 | 119 | 99 | 61 | 47 | 17 | 2 | 4 | 35 | 122 | 29 | 38 | 35 | 17 | 8 | | | | 18 228 | 828 | 81 | .... | .... | .... | .... | ..... |

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12.—WATER PURIFICATION WORKS.—(*Continued.*)

| Day of Month. | Temperature of air, in degrees Fahr. | Temperature of water, in degrees Fahr. | Rainfall, in inches. | Volume of Water. | | Filter Data. | | | | | Applied Chemicals. | | | | | | Color. | | Turbidity. | | | Free carbonic acid, river water. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Pounds. | | | Grains per gallon. | | | | | | | |
| | | | | Pumped, million gal. | Filtered, million gal. | Number used. | Hours in service, average. | Loss of head, maximum, in feet. | Wash-water, percentage. | Use of air. | Lime. | Soda ash. | Coagulant. | Lime. | Soda ash. | Coagulant. | River water. | Filtered water. | River water. | Settled water. | Filtered water. | |
| 1 | 41 | 44 | 0.00 | 13.8 | 12.5 | 10 | 17.1 | 5.8 | 6.1 | 0 | 11 140 | 8 485 | 3 383 | 5.6 | 4.3 | 1.7 | 37 | 0 | 65 | 25 | 0 | + |
| 2 | 48 | 47 | 0.06 | 13.7 | 12.3 | 10 | 18.4 | 4.7 | 4.7 | 0 | 12 000 | 9 540 | 2 595 | 6.1 | 4.9 | 1.3 | 30 | 8 | 52 | 25 | 0 | + |
| 3 | 42 | 43 | 0.01 | 13.1 | 12.6 | 10 | 17.4 | 5.0 | 3.4 | 0 | 12 380 | 9 225 | 2 074 | 6.6 | 4.9 | 1.1 | 33 | — | 44 | 25 | 0 | + |
| 4 | 43 | 47 | 0.00 | 12.5 | 10.8 | 10 | 16.6 | 4.6 | 4.0 | 0 | 11 300 | 9 000 | 1 241 | 6.3 | 5.0 | 0.7 | 33 | 10 | 42 | 25 | 0 | + |
| 5 | 58 | 49 | 0.00 | 12.5 | 12.4 | 10 | 17.4 | 4.8 | 2.8 | 0 | 11 380 | 10 350 | 1 013 | 6.4 | 5.8 | 0.6 | 31 | 2 | 36 | 25 | 0 | + |
| 6 | 60 | 46 | 1.00 | 13.0 | 12.2 | 10 | 17.2 | 4.3 | 4.0 | 0 | 10 880 | 9 990 | 2 922 | 5.9 | 5.4 | 1.6 | 43 | 2 | 148 | 25 | 0 | + |
| 7 | 56 | 51 | 0.00 | 12.8 | 12.0 | 9 | 19.2 | 5.9 | 2.6 | 0 | 10 330 | 7 971 | 8 144 | 5.6 | 5.4 | 4.4 | 70 | 10 | 433 | 25 | 0 | + |
| 8 | 46 | 52 | tr. | 13.5 | 12.8 | 10 | 16.5 | 7.8 | 11.7 | 0 | 8 006 | 2 944 | 13 874 | 4.1 | 1.5 | 7.2 | 80 | 7 | 487 | 72 | 0 | + |
| 9 | 34 | 49 | 0.04 | 14.2 | 12.6 | 10 | 18.2 | 6.2 | 10.1 | 0 | 10 102 | 3 808 | 14 402 | 5.0 | 1.9 | 7.1 | 77 | 11 | 314 | 45 | 0 | + |
| 10 | 31 | 44 | tr. | 12.5 | 12.2 | 10 | 16.9 | 7.8 | 4.1 | 0 | 6 354 | 4 176 | 8 945 | 3.6 | 2.3 | 5.0 | 77 | 12 | 278 | 30 | 0 | + |
| 11 | 39 | 44 | 0.00 | 11.8 | 11.1 | 10 | 15.5 | 8.1 | 10.1 | 0 | 8 280 | 5 848 | 9 460 | 4.9 | 3.5 | 5.6 | 70 | 14 | 178 | 34 | 0 | + |
| 12 | 53 | 47 | 0.00 | 13.2 | 12.4 | 10 | 17.4 | 8.0 | 2.6 | 0 | 9 634 | 9 984 | 10 404 | 5.1 | 5.3 | 5.5 | 67 | 22 | 116 | 25 | 0 | + |
| 13 | 53 | 47 | 0.16 | 11.3 | 11.8 | 10 | 19.6 | 8.0 | 2.0 | 0 | 8 470 | 9 420 | 5 954 | 5.2 | 5.8 | 3.7 | 60 | 19 | 96 | 20 | 0 | + |
| 14 | 42 | 45 | 0.00 | 11.3 | 11.6 | 9 | 17.0 | 7.2 | 0.9 | 0 | 8 064 | 9 630 | 5 286 | 5.0 | 6.0 | 3.3 | 55 | 23 | 74 | 20 | 0 | + |
| 15 | 45 | 47 | 0.00 | 14.3 | 11.8 | 10 | 15.8 | 7.9 | 3.4 | 0 | 13 802 | 14 590 | 5 864 | 6.7 | 7.1 | 2.9 | 50 | 22 | 54 | 20 | 0 | + |
| 16 | 56 | 50 | 0.00 | 13.4 | 12.0 | 8 | 20.8 | 4.2 | 0.7 | 0 | 13 614 | 15 280 | 4 691 | 7.1 | 8.0 | 2.4 | 35 | 16 | 50 | 20 | 0 | + |
| 17 | 64 | 52 | tr. | 14.0 | 12.7 | 9 | 18.0 | 7.2 | 1.4 | 0 | 16 770 | 13 760 | 3 879 | 8.4 | 6.9 | 1.9 | 37 | 12 | 42 | 15 | 0 | + |
| 18 | 66 | 51 | 0.00 | 11.2 | 10.5 | 10 | 15.0 | 8.0 | 1.9 | 0 | 11 232 | 11 681 | 1 655 | 7.0 | 7.3 | 1.0 | 29 | 11 | 29 | 10 | 0 | + |
| 19 | 59 | 56 | 0.03 | 13.7 | 12.1 | 10 | 17.8 | 8.1 | 3.2 | 0 | 15 184 | 15 229 | 1 453 | 7.8 | 7.8 | 0.7 | 33 | 4 | 30 | 10 | 0 | + |
| 20 | 44 | 49 | 0.25 | 12.5 | 11.7 | 10 | 15.0 | 8.0 | 2.0 | 0 | 12 532 | 11 650 | 1 012 | 7.0 | 6.5 | 0.6 | 31 | 3 | 29 | 10 | 0 | + |
| 21 | 55 | 56 | 0.48 | 12.4 | 11.5 | 10 | 16.2 | 8.1 | 1.6 | 0 | 14 638 | 13 800 | 1 147 | 8.3 | 7.8 | 0.6 | 31 | 2 | 31 | 10 | 0 | + |
| 22 | 52 | 54 | 0.00 | 14.2 | 11.5 | 10 | 16.7 | 8.0 | 1.7 | 0 | 14 534 | 14 450 | 2 655 | 7.2 | 7.1 | 1.3 | 31 | 2 | 35 | 10 | 0 | + |
| 23 | 49 | 57 | 0.00 | 12.1 | 11.9 | 10 | 17.9 | 8.1 | 3.2 | 0 | 14 014 | 11 900 | 1 057 | 8.1 | 6.9 | 0.6 | 28 | 1 | 30 | 10 | 0 | + |
| 24 | 46 | 54 | 0.00 | 12.2 | 12.0 | 10 | 19.3 | 4.4 | 3.5 | 0 | 12 636 | 12 550 | 975 | 7.2 | 7.2 | 0.6 | 31 | 1 | 30 | 10 | 0 | + |
| 25 | 60 | 57 | 0.34 | 11.4 | 10.4 | 10 | 18.6 | 3.8 | 3.4 | 0 | 14 040 | 10 950 | 1 028 | 8.6 | 6.7 | 0.6 | 29 | 2 | 35 | 10 | 0 | + |
| 26 | 47 | 54 | 0.00 | 11.7 | 12.4 | 10 | 21.2 | 3.1 | 2.6 | 0 | 12 922 | 12 000 | 2 415 | 7.7 | 7.2 | 1.4 | 32 | 1 | 56 | 10 | 0 | + |
| 27 | 54 | 55 | 0.05 | 12.5 | 11.8 | 10 | 21.1 | 5.5 | 3.2 | 0 | 17 046 | 11 950 | 2 670 | 9.5 | 6.7 | 1.5 | 36 | 1 | 52 | 10 | 0 | + |
| 28 | 45 | 53 | tr. | 12.2 | 11.7 | 10 | 20.0 | 7.8 | 3.9 | 0 | 10 798 | 9 350 | 2 610 | 6.2 | 5.4 | 1.5 | 36 | 1 | 50 | 10 | 0 | + |
| 29 | 60 | 55 | tr. | 12.4 | 12.0 | 10 | 21.1 | 7.0 | 2.8 | 0 | 14 388 | 8 750 | 3 630 | 8.1 | 4.9 | 2.0 | 36 | 2 | 48 | 10 | 0 | + |
| 30 | 62 | 60 | 0.78 | 13.2 | 12.0 | 10 | 20.1 | 4.2 | 3.5 | 0 | 12 078 | 10 447 | 5 147 | 6.4 | 5.5 | 2.7 | 35 | 1 | 96 | 25 | 0 | + |
| Av. | 50 | 50 | .... | 12.7 | 11.9 | 10 | 18.0 | 6.4 | 3.7 | .. | 11 951 | 10 290 | 4 386 | 6.5 | 5.7 | 2.4 | 43 | 8 | 102 | 21 | 0 | + |

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for April, 1909.

| Analytical Results, in Parts per Million. | | | | | | | | | | | | | | | | | | Bacteriological Tests. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total hardness. | | | Total alkalinity. | | | Caustic alk. | | | Mono. carb. alk., filtered water. | Incrust-ants. | | | Magne-sium. | | Bacteria per c. c. | | | Presumptive *Coli* tests. | | | | | | | |
| | | | | | | | | | | | | | | | | | | River water. | | | Filtered water. | | | | |
| River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | Inlet to sett. basin. | Settled water. | Filtered water. | | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Filtered water. | River water. | Settled water. | Filtered water. | 1 c. c. | | 1 c. c. | | 50 c.c. |
| | | | | | | | | | | | | | | | | | | | | | Smith method. | Bile method. | Smith method. | Bile method. | Smith method. |
| 224 | 123 | 102 | 74 | 117 | 74 | 54 | 37 | 10 | 0 | 3 | 34 | 107 | 49 | 48 | 37 | 18 | 10 | 2 700 | 250 | 4 | 0 | 0 | 0 | 0 | 0 |
| 247 | 123 | 101 | 99 | 122 | 69 | 49 | 44 | 7 | 0 | 0 | 26 | 125 | 53 | 52 | 55 | 19 | 13 | 1 500 | 250 | 95 | 0 | + | 0 | 0 | 0 |
| 252 | 116 | 106 | 90 | 125 | 72 | 50 | 38 | 12 | 0 | 0 | 30 | 127 | 44 | 56 | 52 | 19 | 11 | 1 500 | 90 | 60 | + | 0 | 0 | 0 | 0 |
| 259 | 120 | 96 | 96 | 128 | 68 | 45 | 40 | 12 | 1 | 0 | 28 | 131 | 52 | 51 | 56 | 17 | 8 | 725 | 130 | 1 | 0 | 0 | 0 | 0 | 0 |
| 260 | 108 | 100 | 87 | 130 | 72 | 46 | 36 | 2 | 2 | 0 | 32 | 130 | 36 | 53 | 52 | 21 | 7 | 700 | 20 | 2 | 0 | 0 | 0 | 0 | 0 |
| 271 | 113 | 97 | 91 | 137 | 66 | 49 | 39 | 8 | 0 | 0 | 38 | 134 | 47 | 48 | 52 | 22 | 9 | 13 500 | 50 | 10 | + | + | 0 | 0 | 0 |
| 181 | 122 | 107 | 87 | 94 | 78 | 54 | 41 | 16 | 0 | 0 | 38 | 87 | 44 | 53 | 46 | 18 | 11 | 68 000 | 1 000 | 45 | + | + | 0 | 0 | 0 |
| 138 | 133 | 106 | 115 | 81 | 89 | 53 | 48 | 11 | 0 | 0 | 22 | 58 | 43 | 53 | 57 | 17 | 15 | 38 000 | 3 000 | 80 | 0 | 0 | 0 | 0 | 0 |
| 147 | 124 | 93 | 121 | 87 | 96 | 41 | 46 | 16 | 0 | 0 | 8 | 60 | 28 | 52 | 76 | 18 | 12 | 40 000 | 1 700 | 295 | 0 | + | 0 | 0 | 0 |
| 148 | 127 | 113 | 125 | 87 | 99 | 40 | 45 | 0 | 0 | 0 | 2 | 61 | 28 | 73 | 80 | 14 | 8 | 25 000 | 2 000 | 290 | + | 0 | 0 | + | 0 |
| 158 | 118 | 126 | 129 | 95 | 102 | 59 | 46 | 12 | 0 | 0 | 2 | 63 | 16 | 67 | 74 | 16 | 7 | 10 000 | 80 | 300 | + | + | 0 | 0 | 0 |
| 189 | 118 | 103 | 109 | 101 | 78 | 51 | 47 | 26 | 0 | 0 | 0 | 88 | 40 | 53 | 62 | 21 | 10 | 12 000 | 200 | 210 | + | + | 0 | 0 | 0 |
| 211 | 104 | 100 | 100 | 109 | 91 | 54 | 47 | 9 | 0 | 0 | 6 | 102 | 13 | 46 | 52 | 18 | 13 | 8 000 | 2 000 | 150 | + | + | 0 | 0 | 0 |
| 221 | 119 | 95 | 90 | 116 | 75 | 68 | 57 | 17 | 0 | 0 | 14 | 105 | 44 | 27 | 32 | 16 | 10 | 2 500 | 155 | 110 | + | + | 0 | 0 | 0 |
| 244 | 131 | 104 | 91 | 129 | 60 | 70 | 60 | 30 | 0 | 0 | 20 | 116 | 71 | 34 | 31 | 18 | 9 | 1 000 | 86 | 20 | + | + | 0 | 0 | + |
| 247 | 98 | 84 | 94 | 135 | 90 | 66 | 64 | 22 | 0 | 0 | 30 | 112 | 8 | 18 | 30 | 19 | 11 | 500 | 16 | 15 | 0 | 0 | 0 | 0 | 0 |
| 262 | 98 | 77 | 77 | 140 | 82 | 65 | 63 | 26 | 0 | 0 | 36 | 122 | 11 | 12 | 14 | 21 | 13 | 1 500 | 190 | 160 | 0 | 0 | 0 | 0 | 0 |
| 290 | 116 | 77 | 65 | 155 | 66 | 53 | 55 | 28 | 0 | 0 | 38 | 135 | 50 | 24 | 10 | 20 | 9 | 1 500 | 110 | 90 | 0 | 0 | 0 | 0 | 0 |
| 278 | 115 | 83 | 67 | 149 | 73 | 60 | 46 | 33 | 0 | 0 | 34 | 129 | 42 | 23 | 21 | 19 | 7 | 1 000 | 500 | 200 | 0 | 0 | 0 | 0 | 0 |
| 293 | 110 | 69 | 63 | 158 | 78 | 58 | 55 | 0 | 0 | 0 | 40 | 134 | 32 | 11 | 7 | 19 | 7 | 1 500 | 325 | 310 | 0 | 0 | 0 | 0 | 0 |
| 298 | 108 | 92 | 70 | 154 | 77 | 55 | 48 | 17 | 0 | 0 | 40 | 139 | 26 | 37 | 22 | 21 | 8 | 7 500 | 1 750 | 350 | + | + | 0 | 0 | 0 |
| 287 | 104 | 80 | 72 | 154 | 85 | 52 | 48 | 3 | 0 | 0 | 40 | 133 | 19 | 28 | 24 | 21 | 10 | 300 | 2 000 | 600 | + | + | 0 | 0 | 0 |
| 289 | 118 | 91 | 73 | 156 | 84 | 51 | 43 | 0 | 0 | 0 | 38 | 133 | 34 | 40 | 30 | 23 | 10 | 1 250 | 5 000 | 70 | 0 | 0 | 0 | 0 | 0 |
| 297 | 106 | 83 | 66 | 162 | 82 | 56 | 42 | 0 | 0 | 0 | 34 | 135 | 24 | 27 | 24 | 23 | 10 | 1 750 | 1 250 | 1 100 | + | + | 0 | 0 | 0 |
| 291 | 109 | 86 | 67 | 164 | 73 | 58 | 45 | 9 | 0 | 0 | 38 | 127 | 36 | 28 | 21 | 22 | 10 | 1 500 | 1 600 | 900 | + | 0 | 0 | 0 | 0 |
| 276 | 109 | 87 | 75 | 157 | 88 | 52 | 48 | 6 | 0 | 0 | 42 | 119 | 21 | 35 | 28 | 22 | 11 | 2 000 | 1 000 | 1 250 | + | + | 0 | 0 | + |
| 262 | 90 | 66 | 66 | 148 | 81 | 48 | 40 | 39 | 0 | 0 | 32 | 114 | 9 | 18 | 26 | 22 | 9 | 1 150 | 130 | 50 | + | + | 0 | 0 | 0 |
| 259 | 102 | 68 | 57 | 150 | 75 | 52 | 40 | 11 | 6 | 0 | 32 | 109 | 28 | 16 | 17 | 19 | 7 | 1 850 | 175 | 450 | 0 | 0 | 0 | 0 | 0 |
| 248 | 99 | 83 | 52 | 144 | 75 | 52 | 36 | 13 | 0 | 0 | 30 | 104 | 24 | 31 | 16 | 19 | 5 | 1 900 | 280 | 225 | 0 | 0 | 0 | 0 | 0 |
| 248 | 108 | 78 | 66 | 142 | 61 | 42 | 40 | 13 | 0 | 0 | 28 | 106 | 42 | 35 | 26 | 18 | 8 | 4 700 | 650 | 480 | 0 | 0 | 0 | 0 | 0 |
| 242 | 112 | 92 | 84 | 131 | 79 | 53 | 46 | 18 | 0.3 | 0.1 | 28 | 111 | 34 | 38 | 38 | 19 | 10 | 8 500 | 8 662 | 264 | .... | .... | .... | .... | ..... |

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12.—WATER PURIFICATION WORKS.—(*Continued.*)

| Day of Month. | Temperature of air, in degrees Fahr. | Temperature of water, in degrees Fahr. | Rainfall, in inches. | Volume of Water. | | Filter Data. | | | | | Applied Chemicals. | | | | | | Color. | | Turbidity. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Pounds. | | | Grains per gallon. | | | | | | | | |
| | | | | Pumped, million gal. | Filtered, million gal. | Number used. | Hours in service, average. | Loss of head, maximum, in feet. | Wash-water, percentage. | Use of air. | Lime. | Soda ash. | Coagulant. | Lime. | Soda ash. | Coagulant. | River water. | Filtered water. | River water. | Settled water. | Filtered water. | Free carbonic acid, river water. |
| 1 | 46 | 57 | tr. | 12.5 | 11.8 | 10 | 20.9 | 7.0 | 2.3 | 0 | 8 754 | 4 878 | 12 648 | 4.9 | 2.7 | 7.1 | 67 | 3 | 1 017 | 30 | 0 | 3 |
| 2 | 45 | 53 | tr. | 11.1 | 10.3 | 10 | 17.3 | 9.3 | 3.8 | 0 | 5 680 | 4 225 | 13 150 | 3.6 | 2.7 | 8.3 | 65 | 2 | 1 081 | 30 | 0 | 4 |
| 3 | 47 | 51 | 0.36 | 11.8 | 12.0 | 10 | 20.0 | 8.1 | 6.9 | 0 | 7 040 | 3 900 | 11 556 | 4.2 | 2.3 | 6.8 | 70 | 2 | 485 | 35 | 0 | 3 |
| 4 | 45 | 49 | 0.50 | 13.0 | 13.0 | 10 | 20.2 | 8.1 | 10.8 | 0 | 8 865 | 4 140 | 15 464 | 4.8 | 2.2 | 8.3 | 70 | 4 | 297 | 104 | 0 | 4 |
| 5 | 57 | 50 | 0.17 | 13.0 | 12.5 | 10 | 21.0 | 8.1 | 7.3 | 0 | 8 739 | 8 645 | 8 990 | 4.7 | 4.6 | 4.8 | 60 | 6 | 199 | 67 | 0 | 4 |
| 6 | 66 | 52 | 0.00 | 13.0 | 12.3 | 10 | 21.6 | 8.0 | 6.4 | 0 | 12 296 | 8 735 | 5 870 | 6.6 | 4.7 | 3.2 | 47 | 18 | 140 | 38 | 0 | 3 |
| 7 | 59 | 56 | 0.01 | 14.1 | 12.0 | 10 | 22.2 | 8.0 | 4.9 | 0 | 14 850 | 9 140 | 4 840 | 7.4 | 4.5 | 2.4 | 55 | 18 | 114 | 25 | 0 | 3 |
| 8 | 67 | 59 | 0.00 | 12.6 | 12.4 | 10 | 19.1 | 8.0 | 2.5 | 0 | 12 055 | 7 300 | 3 985 | 6.7 | 4.1 | 2.2 | 39 | 13 | 97 | 25 | 0 | 3 |
| 9 | 66 | 63 | 0.52 | 12.0 | 10.5 | 10 | 18.1 | 8.0 | 4.9 | 0 | 14 525 | 7 420 | 6 007 | 8.5 | 4.3 | 3.5 | 37 | 5 | 88 | 25 | 0 | 3 |
| 10 | 51 | 61 | 0.94 | 12.4 | 11.9 | 10 | 20.5 | 8.1 | 4.2 | 0 | 14 070 | 5 500 | 11 908 | 7.9 | 3.1 | 6.7 | 45 | 8 | 377 | 25 | 0 | 4 |
| 11 | 52 | 57 | 0.00 | 12.7 | 12.6 | 10 | 18.5 | 8.8 | 5.8 | 0 | 12 870 | 4 080 | 20 350 | 7.1 | 2.2 | 11.2 | 70 | 2 | 478 | 25 | 0 | 3 |
| 12 | 60 | 54 | 0.00 | 12.6 | 12.8 | 10 | 20.6 | 7.7 | 6.3 | 0 | 14 610 | 3 720 | 14 750 | 8.1 | 2.1 | 8.2 | — | 10 | 304 | 25 | 0 | 3 |
| 13 | 61 | 57 | tr. | 13.8 | 12.3 | 10 | 21.1 | 7.2 | 4.7 | 0 | 13 375 | 4 340 | 9 450 | 6.8 | 2.2 | 4.8 | 60 | 12 | 216 | 30 | 0 | 3 |
| 14 | 68 | 59 | 0.00 | 13.6 | 12.9 | 10 | 20.1 | 7.5 | 3.9 | 0 | 8 295 | 4 320 | 7 890 | 4.3 | 2.2 | 4.0 | 80 | 12 | 134 | 25 | 0 | 3 |
| 15 | 70 | 61 | 0.23 | 13.5 | 13.2 | 10 | 21.2 | 7.1 | 6.0 | 0 | 11 480 | 4 260 | 6 340 | 5.9 | 2.2 | 3.3 | 62 | 14 | 109 | 34 | 0 | 4 |
| 16 | 65 | 63 | 0.00 | 12.4 | 11.0 | 10 | 18.1 | 7.0 | 7.8 | 0 | 11 500 | 3 980 | 3 958 | 6.5 | 2.2 | 2.2 | 62 | 21 | 85 | 30 | 0 | 3 |
| 17 | 63 | 66 | 0.00 | 13.3 | 13.3 | 10 | 21.2 | 7.1 | 3.8 | 0 | 13 040 | 5 820 | 2 522 | 6.9 | 3.1 | 1.3 | 62 | 16 | 68 | 30 | 0 | 4 |
| 18 | 60 | 65 | 0.00 | 14.0 | 12.8 | 10 | 20.5 | 7.1 | 3.9 | 0 | 14 970 | 7 250 | 3 510 | 7.5 | 3.6 | 1.8 | 55 | 17 | 53 | 30 | 0 | 3 |
| 19 | 60 | 66 | 0.00 | 13.5 | 13.2 | 10 | 21.3 | 7.1 | 6.5 | 0 | 17 929 | 8 250 | 5 230 | 9.3 | 4.3 | 2.7 | 41 | 13 | 46 | 25 | 0 | 3 |
| 20 | 57 | 62 | 0.99 | 13.3 | 12.3 | 10 | 21.7 | 7.0 | 5.8 | 0 | 18 201 | 7 945 | 4 580 | 9.6 | 4.2 | 2.4 | 42 | 11 | 40 | 20 | 0 | 3 |
| 21 | 58 | 63 | 0.11 | 12.9 | 12.7 | 10 | 19.0 | 7.0 | 5.3 | 0 | 16 512 | 7 255 | 7 060 | 9.0 | 3.9 | 3.8 | 42 | 12 | 53 | 20 | 0 | 3 |
| 22 | 60 | 62 | 0.00 | 12.3 | 12.2 | 10 | 20.2 | 7.0 | 4.9 | 0 | 13 980 | 7 350 | 7 494 | 7.9 | 4.2 | 4.3 | 42 | 10 | 53 | 20 | 0 | 3 |
| 23 | 60 | 62 | 0.00 | 13.3 | 10.8 | 10 | 19.1 | 7.0 | 4.7 | 0 | 13 620 | 7 890 | 6 748 | 7.2 | 4.1 | 3.5 | 55 | 9 | 63 | 20 | 0 | 3 |
| 24 | 61 | 61 | 0.00 | 12.6 | 13.1 | 10 | 20.6 | 7.0 | 4.8 | 0 | 12 920 | 6 690 | 5 684 | 7.2 | 3.7 | 3.2 | 52 | 8 | 50 | 15 | 0 | 3 |
| 25 | 61 | 62 | 0.07 | 13.3 | 13.3 | 10 | 19.3 | 7.0 | 8.6 | 0 | 13 720 | 7 170 | 4 774 | 7.2 | 3.8 | 2.5 | 38 | 8 | 48 | 15 | 0 | 3 |
| 26 | 66 | 63 | 0.10 | 14.7 | 13.3 | 10 | 20.8 | 7.2 | 8.3 | 0 | 16 706 | 8 130 | 4 354 | 7.9 | 3.9 | 2.1 | 40 | 12 | 48 | 15 | 0 | 3 |
| 27 | 69 | 62 | 0.08 | 15.8 | 13.2 | 10 | 21.6 | 8.5 | 7.3 | 0 | 16 829 | 9 390 | 3 442 | 7.4 | 4.2 | 1.5 | 52 | 13 | 48 | 15 | 0 | 3 |
| 28 | 65 | 65 | 0.00 | 15.1 | 13.9 | 10 | 22.6 | 8.1 | 4.9 | 0 | 17 637 | 8 730 | 2 062 | 8.2 | 4.0 | 1.0 | 40 | 12 | 36 | 10 | 0 | 3 |
| 29 | 69 | 68 | 0.00 | 15.0 | 13.8 | 10 | 21.7 | 8.0 | 2.2 | 0 | 18 008 | 8 400 | 2 088 | 8.4 | 3.9 | 1.0 | 46 | 12 | 59 | 10 | 0 | 3 |
| 30 | 68 | 66 | 0.57 | 12.0 | 10.7 | 10 | 15.8 | 8.0 | 5.5 | 0 | 14 880 | 5 490 | 2 292 | 8.4 | 3.2 | 1.3 | 47 | 12 | 101 | 10 | 0 | 4 |
| 31 | 72 | 66 | 0.00 | 13.6 | 12.2 | 10 | 17.3 | 7.0 | 4.2 | 0 | 11 915 | 5 880 | 3 444 | 6.1 | 3.0 | 1.8 | 57 | 13 | 108 | 30 | 0 | 4 |
| Av. | 60 | 60 | .... | 13.2 | 12.4 | 10 | 20.1 | 7.6 | 5.5 | .. | 13 206 | 6 459 | 7 173 | 7.0 | 3.4 | 3.9 | 53 | 11 | 196 | 28 | 0 | 3 |

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for May, 1909.

| Analytical Results, in Parts per Million. | | | | | | | | | | | | | | | | | | Bacteriological Tests. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total hardness. | | | | Total alkalinity. | | | | Caustic alk. | | | Mono. carb. alk., filtered water. | Incrustants. | | | | Magnesium. | | Bacteria per c. c. | | | Presumptive *Coli* tests. | | | |
| | | | | | | | | | | | | | | | | | | | | | River water. | | | |
| | | | | | | | | | | | | | | | | | | | | | 1 c. c. | | | 50 c.c. |
| River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | Inlet to sett. basin. | Settled water. | Filtered water. | | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Filtered water. | River water. | Settled water. | Filtered water. | Smith method. | Bile method. | Smith method. | Bile method. | Smith method. |
| 140 | 110 | 90 | 65 | 91 | 86 | 48 | 39 | 10 | 0 | 0 | 24 | 49 | 24 | 42 | 26 | 16 | 8 | 87 500 | 1 150 | 560 | 0 | 0 | 0 | 0 | 0 |
| 92 | 112 | 115 | 100 | 62 | 112 | 40 | 41 | 0 | 0 | 0 | 12 | 30 | 0 | 75 | 59 | 11 | 10 | 86 000 | 2 000 | 600 | + | + | 0 | 0 | 0 |
| 89 | 117 | 105 | 114 | 70 | 115 | 47 | 49 | 0 | 0 | 0 | 6 | 19 | 2 | 58 | 65 | 10 | 7 | 32 000 | 2 800 | 475 | 0 | + | + | 0 | + |
| 121 | 128 | 88 | 123 | 82 | 85 | 56 | 58 | 0 | 0 | 0 | 0 | 39 | 43 | 32 | 65 | 12 | 6 | 30 000 | 4 200 | 675 | + | + | 0 | 0 | + |
| 167 | 103 | 101 | 114 | 97 | 60 | 65 | 51 | 0 | 0 | 0 | 0 | 70 | 43 | 36 | 63 | 12 | 5 | 18 500 | 7 500 | 500 | + | + | 0 | 0 | + |
| 187 | 100 | 95 | 98 | 110 | 81 | 65 | 50 | 0 | 0 | 0 | 4 | 77 | 18 | 30 | 48 | 15 | 7 | 15 600 | 8 200 | 2 000 | + | + | 0 | 0 | 0 |
| 202 | 85 | 86 | 92 | 122 | 61 | 58 | 55 | 9 | 0 | 0 | 10 | 81 | 24 | 28 | 37 | 13 | 8 | 6 100 | 6 750 | 2 600 | + | 0 | 0 | 0 | 0 |
| 209 | 74 | 64 | 69 | 127 | 52 | 44 | 44 | 0 | 0 | 0 | 24 | 82 | 22 | 20 | 25 | 16 | 7 | 3 200 | 7 500 | 5 850 | + | + | 0 | 0 | 0 |
| 218 | 83 | 69 | 67 | 131 | 51 | 48 | 42 | 0 | 0 | 0 | 22 | 87 | 32 | 21 | 25 | 16 | 7 | 2 000 | 2 600 | 1 600 | 0 | 0 | 0 | 0 | 0 |
| 160 | 74 | 64 | 69 | 105 | 63 | 41 | 38 | 7 | 0 | 0 | 16 | 56 | 11 | 23 | 32 | 13 | 6 | 29 400 | 4 900 | 1 300 | + | + | 0 | 0 | 0 |
| 94 | 141 | 75 | 74 | 67 | 113 | 46 | 33 | 27 | 0 | 0 | 8 | 27 | 28 | 29 | 42 | 9 | 7 | 77 000 | 16 400 | 1 050 | 0 | + | 0 | 0 | 0 |
| 95 | 124 | 106 | 93 | 72 | 107 | 51 | 33 | 51 | 0 | 0 | 6 | 22 | 17 | 55 | 60 | 7 | 5 | 35 000 | 36 500 | 1 275 | + | + | 0 | 0 | 0 |
| 115 | 105 | 105 | 98 | 83 | 91 | 68 | 40 | 27 | 0 | 0 | 14 | 32 | 14 | 37 | 57 | 9 | 4 | 24 400 | 250 | 50 | + | + | 0 | 0 | 0 |
| 118 | 108 | 93 | 83 | 91 | 74 | 56 | 49 | 8 | 10 | 3 | 46 | 27 | 34 | 37 | 34 | 10 | 4 | 13 750 | 200 | 275 | + | + | 0 | 0 | 0 |
| 164 | 113 | 83 | 74 | 103 | 80 | 51 | 46 | 2 | 0 | 1 | 45 | 61 | 32 | 32 | 28 | 12 | 6 | 3 500 | 175 | 100 | + | + | 0 | 0 | 0 |
| 191 | 112 | 92 | 83 | 111 | 59 | 53 | 39 | 9 | 0 | 0 | 22 | 80 | 52 | 39 | 44 | 11 | 6 | 2 100 | 850 | 425 | + | + | 0 | 0 | 0 |
| 215 | 105 | 100 | 85 | 123 | 60 | 52 | 35 | 8 | 8 | 0 | 30 | 92 | 45 | 48 | 50 | 16 | 6 | 1 400 | 2 000 | 1 000 | + | 0 | 0 | 0 | 0 |
| 232 | 109 | 100 | 86 | 135 | 61 | 53 | 36 | 0 | 0 | 1 | 35 | 98 | 48 | 47 | 50 | 15 | 8 | 1 500 | 1 600 | 600 | + | + | 0 | 0 | 0 |
| 242 | 100 | 98 | 86 | 140 | 58 | 54 | 36 | 18 | 0 | 0 | 34 | 102 | 43 | 44 | 50 | 17 | 8 | 1 200 | 1 500 | 550 | + | + | 0 | 0 | 0 |
| 248 | 108 | 116 | 90 | 145 | 63 | 57 | 37 | 3 | 1 | 0 | 30 | 103 | 44 | 59 | 53 | 19 | 8 | 1 300 | 1 000 | 250 | 0 | + | 0 | 0 | 0 |
| 246 | 98 | 97 | 78 | 140 | 57 | 56 | 37 | 21 | 6 | 0 | 30 | 106 | 41 | 41 | 41 | 17 | 7 | 2 100 | 200 | 110 | 0 | + | 0 | 0 | 0 |
| 255 | 97 | 110 | 86 | 146 | 56 | 59 | 30 | 8 | 19 | 0 | 26 | 109 | 40 | 51 | 56 | 18 | 7 | 3 250 | 125 | 110 | + | + | 0 | 0 | 0 |
| 222 | 98 | 98 | 90 | 131 | 71 | 46 | 27 | 27 | 2 | 0 | 24 | 91 | 22 | 52 | 63 | 19 | 10 | 7 400 | 110 | 10 | + | + | 0 | 0 | 0 |
| 218 | 94 | 76 | 79 | 135 | 67 | 56 | 30 | 17 | 4 | 0 | 24 | 83 | 27 | 20 | 49 | 15 | 9 | 4 100 | 75 | 45 | + | 0 | 0 | 0 | 0 |
| 228 | 93 | 91 | 71 | 144 | 67 | 58 | 33 | 1 | 8 | 0 | 32 | 84 | 26 | 33 | 37 | 20 | 8 | 2 650 | 85 | 48 | 0 | + | 0 | 0 | 0 |
| 234 | 100 | 90 | 75 | 142 | 63 | 58 | 38 | 1 | 0 | 0 | 34 | 92 | 37 | 33 | 37 | 19 | 9 | 1 100 | 50 | 38 | + | + | 0 | 0 | 0 |
| 223 | 89 | 96 | 67 | 139 | 67 | 63 | 39 | 1 | 0 | 1 | 38 | 84 | 21 | 33 | 27 | 17 | 9 | 1 250 | 35 | 20 | + | + | 0 | 0 | 0 |
| 239 | 84 | 82 | 65 | 153 | 50 | 56 | 41 | 4 | 0 | 4 | 37 | 86 | 34 | 26 | 24 | 17 | 8 | 2 300 | 74 | 38 | 0 | 0 | 0 | 0 | 0 |
| 249 | 97 | 90 | 73 | 160 | 62 | 56 | 43 | 4 | 0 | 1 | 42 | 89 | 34 | 34 | 30 | 22 | 11 | 3 300 | 120 | 21 | 0 | + | 0 | 0 | 0 |
| 217 | 79 | 83 | 69 | 142 | 58 | 59 | 44 | 18 | 0 | 0 | 38 | 75 | 21 | 25 | 25 | 16 | 9 | 4 570 | 158 | 65 | + | + | 0 | 0 | 0 |
| 203 | 82 | 86 | 70 | 128 | 60 | 58 | 42 | 2 | 6 | 0 | 40 | 75 | 23 | 27 | 28 | 16 | 9 | 2 100 | 100 | 24 | + | + | 0 | 0 | 0 |
| 188 | 101 | 92 | 83 | 117 | 71 | 54 | 40 | 9 | 2 | 0.3 | 24 | 71 | 29 | 38 | 43 | 15 | 7 | 16 309 | 3 523 | 718 | .... | .... | .... | .... | ..... |

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12.—WATER PURIFICATION WORKS.—(*Continued.*)

| Day of Month. | Temperature of air, in degrees Fahr. | Temperature of water, in degrees Fahr. | Rainfall, in inches. | Volume of Water. | | Filter Data. | | | | | Applied Chemicals. | | | | | | Color. | | Turbidity. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Pumped, million gal. | Filtered, million gal. | Number used. | Hours in service, average. | Loss of head, maximum, in feet. | Wash-water, percentage. | Use of air. | Pounds. | | | Grains per gallon. | | | River water. | Filtered water. | River water. | Settled water. | Filtered water. | Free carbonic acid, river water. |
| | | | | | | | | | | | Lime. | Soda ash. | Coagulant. | Lime. | Soda ash. | Coagulant. | | | | | | |
| 1 | 74 | 69 | 0.00 | 15.1 | 14.3 | 10 | 19.0 | 6.6 | 1.7 | 0 | 15 705 | 6 720 | 3 328 | 7.3 | 3.1 | 1.5 | 67 | 12 | 100 | 5 | 0 | 3 |
| 2 | 72 | 72 | 0.25 | 14.3 | 12.9 | 10 | 19.6 | 7.4 | 3.1 | 0 | 14 310 | 6 180 | 2 796 | 7.0 | 3.0 | 1.4 | 62 | 15 | 65 | 5 | 0 | 3 |
| 3 | 70 | 70 | 0.01 | 14.6 | 13.1 | 10 | 18.1 | 8.0 | 1.4 | 0 | 14 786 | 5 803 | 2 700 | 7.1 | 2.8 | 1.3 | 60 | 16 | 53 | 5 | 0 | 4 |
| 4 | 71 | 71 | 0.07 | 14.9 | 13.0 | 10 | 20.7 | 8.0 | 1.6 | 0 | 13 568 | 5 522 | 2 292 | 6.4 | 2.6 | 1.1 | 57 | 15 | 51 | 5 | 0 | 3 |
| 5 | 70 | 72 | 0.07 | 13.2 | 13.1 | 10 | 19.1 | 6.5 | 3.4 | 0 | 14 336 | 5 150 | 1 964 | 7.6 | 2.7 | 1.0 | 45 | 16 | 46 | 5 | 0 | 3 |
| 6 | 69 | 70 | 0.00 | 11.2 | 10.7 | 9 | 17.1 | 6.3 | 2.2 | 0 | 11 799 | 3 248 | 6 588 | 7.4 | 2.0 | 4.1 | 75 | 19 | 254 | 5 | 0 | 2 |
| 7 | 76 | 71 | tr. | 13.3 | 13.6 | 10 | 20.6 | 7.8 | 1.5 | 0 | 9 153 | 0 | 9 636 | 4.8 | 0 | 5.1 | 87 | 15 | 283 | 5 | 0 | 3 |
| 8 | 75 | 72 | 0.67 | 14.7 | 13.6 | 10 | 19.9 | 7.9 | 5.0 | 0 | 11 908 | 0 | 7 440 | 5.7 | 0 | 3.5 | 100 | 16 | 182 | 25 | 0 | 3 |
| 9 | 70 | 72 | tr. | 13.2 | 13.7 | 9 | 21.4 | 7.9 | 4.1 | 0 | 11 000 | 0 | 5 088 | 5.8 | 0 | 2.7 | 100 | 15 | 154 | 25 | 0 | 3 |
| 10 | 70 | 72 | 0.24 | 12.6 | 12.3 | 9 | 19.8 | 8.0 | 2.2 | 0 | 10 980 | 0 | 5 520 | 6.1 | 0 | 3.1 | 62 | 17 | 108 | 25 | 0 | 3 |
| 11 | 69 | 71 | tr. | 13.8 | 13.1 | 9 | 21.9 | 8.9 | 2.9 | 0 | 13 080 | 0 | 4 968 | 6.6 | 0 | 2.5 | 67 | 17 | 121 | 25 | 0 | 3 |
| 12 | 69 | 67 | 0.00 | 13.7 | 13.1 | 9 | 20.4 | 7.9 | 1.8 | 0 | 11 760 | 1 835 | 5 016 | 6.0 | 0.9 | 2.6 | 75 | 17 | 142 | 25 | 0 | 3 |
| 13 | 73 | 72 | 0.00 | 12.1 | 11.0 | 9 | 18.9 | 7.9 | 4.7 | 0 | 9 780 | 2 841 | 3 720 | 5.7 | 1.6 | 2.1 | 82 | 18 | 102 | 25 | 0 | 3 |
| 14 | 75 | 72 | 0.00 | 13.2 | 14.3 | 9 | 22.1 | 8.0 | 2.3 | 0 | 11 040 | 2 985 | 3 504 | 5.8 | 1.6 | 1.9 | 100 | 26 | 89 | 25 | 0 | 3 |
| 15 | 66 | 72 | 0.00 | 15.0 | 14.0 | 9 | 22.4 | 8.0 | 3.3 | 0 | 12 495 | 3 277 | 3 849 | 5.8 | 1.5 | 1.8 | 110 | 26 | 51 | 25 | 0 | 3 |
| 16 | 70 | 74 | 0.00 | 13.2 | 13.9 | 9 | 23.0 | 8.0 | 1.6 | 0 | 11 865 | ≥ 587 | 3 382 | 6.3 | 1.4 | 1.8 | 90 | 32 | 35 | 25 | 0 | 3 |
| 17 | 68 | 71 | 0.30 | 14.3 | 13.8 | 9 | 21.5 | 7.6 | 1.7 | 0 | 12 915 | 2 730 | 3 631 | 6.3 | 1.3 | 1.5 | 94 | 28 | 31 | 25 | 0 | 3 |
| 18 | 62 | 70 | 0.00 | 14.0 | 13.1 | 9 | 22.1 | 7.9 | 2.2 | 0 | 13 005 | 2 743 | 2 277 | 6.5 | 1.4 | 1.1 | 110 | 35 | 26 | 25 | 0 | 3 |
| 19 | 63 | 69 | 0.00 | 13.3 | 14.2 | 9 | 22.4 | 5.7 | 0.8 | 0 | 12 810 | 2 886 | 1 764 | 6.7 | 1.5 | 0.9 | 105 | 30 | 25 | 25 | 0 | 3 |
| 20 | 71 | 71 | 0.00 | 12.7 | 11.3 | 9 | 20.8 | 5.2 | 1.5 | 0 | 12 120 | 3 029 | 585 | 6.7 | 1.7 | 0.3 | 120 | 25 | 25 | 25 | 0 | 3 |
| 21 | 74 | 74 | 0.32 | 12.4 | 13.6 | 9 | 22.9 | 4.9 | 0.4 | 0 | 11 850 | 3 237 | 579 | 6.7 | 1.8 | 0.3 | 135 | 28 | 25 | 12 | 0 | 3 |
| 22 | 74 | 74 | 0.03 | 14.7 | 13.3 | 9 | 20.7 | 7.1 | 2.6 | 0 | 14 205 | 4 017 | 889 | 6.8 | 1.9 | 0.4 | 110 | 23 | 23 | 5 | 0 | 3 |
| 23 | 76 | 74 | 1.01 | 14.1 | 13.7 | 9 | 22.3 | 7.7 | 5.7 | 0 | 14 100 | 3 998 | 308 | 7.0 | 2.0 | 0.2 | 100 | 18 | 22 | 5 | 0 | 3 |
| 24 | 77 | 73 | 0.12 | 15.4 | 13.2 | 9 | 22.8 | 7.0 | 3.3 | 0 | 15 975 | 5 010 | 3 871 | 7.3 | 2.3 | 1.8 | 55 | 15 | 80 | 5 | 0 | 3 |
| 25 | 73 | 73 | 0.49 | 14.2 | 14.4 | 9 | 22.2 | 6.9 | 1.5 | 0 | 16 542 | 4 891 | 2 996 | 8.1 | 2.4 | 1.5 | 40 | 17 | 30 | 5 | 0 | 3 |
| 26 | 79 | 75 | 0.00 | 13.6 | 14.0 | 9 | 22.8 | 5.1 | 0.6 | 0 | 16 126 | 6 295 | 3 106 | 8.3 | 3.2 | 1.6 | 42 | 17 | 52 | 5 | 0 | 3 |
| 27 | 80 | 78 | 0.23 | 12.4 | 11.8 | 9 | 19.0 | 6.9 | 2.4 | 0 | 15 927 | 6 510 | 2 978 | 9.0 | 3.7 | 1.7 | 28 | 3 | 36 | 5 | 0 | 3 |
| 28 | 78 | 78 | 0.07 | 14.3 | 14.6 | 9 | 23.1 | 7.0 | 2.7 | 0 | 16 168 | 7 620 | 5 892 | 7.9 | 3.7 | 2.9 | 40 | 5 | 175 | 5 | 0 | 3 |
| 29 | 77 | 78 | 0.00 | 15.7 | 13.6 | 9 | 22.4 | 7.0 | 3.2 | 0 | 14 259 | 3 650 | 5 940 | 6.4 | 1.6 | 2.6 | 55 | 3 | 206 | 5 | 0 | 3 |
| 30 | 74 | 77 | 0.00 | 14.5 | 14.1 | 9 | 21.0 | 5.0 | 3.1 | 0 | 13 357 | 0 | 5 960 | 6.4 | 0 | 2.9 | 60 | 5 | 168 | 5 | 0 | 3 |
| Av. | 72 | 72 | .... | 13.8 | 13.3 | 9 | 21.0 | 7.1 | 2.5 | .. | 13 231 | 3 425 | 3 728 | 6.7 | 1.7 | 1.9 | 78 | 18 | 92 | 14 | 0 | 3 |

\+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for June, 1909.

| Analytical Results, in Parts per Million. | | | | | | | | | | | | | | | | | | Bacteriological Tests. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total hardness. | | | | Total alkalinity. | | | | Caustic alk. | | | Mono. carb. alk., filtered water. | Incrustants. | | | | Magnesium. | | Bacteria per c. c. | | | Presumptive *Coli* tests. | | | |
| | | | | | | | | | | | | | | | | | | | | | River water. | | Filtered water. | |
| | | | | | | | | | | | | | | | | | | | | | 1 c. c. | | 1 c. c. | 50 c. c. |
| River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | Inlet to sett. basin. | Settled water. | Filtered water. | | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Filtered water. | River water. | Settled water. | Filtered water. | Smith method. | Bile method. | Smith method. | Bile method. | Smith method. |
| 192 | 81 | 78 | 59 | 122 | 64 | 55 | 38 | 2 | 0 | 1 | 36 | 70 | 17 | 23 | 21 | 14 | 7 | 1 600 | 40 | 17 | + | + | 0 | 0 | 0 |
| 204 | 81 | 82 | 62 | 132 | 55 | 57 | 41 | 3 | 0 | 1 | 40 | 72 | 26 | 25 | 22 | 14 | 6 | 1 250 | 105 | 40 | 0 | 0 | 0 | 0 | 0 |
| 212 | 89 | 80 | 63 | 139 | 56 | 54 | 41 | 0 | 0 | 3 | 38 | 72 | 33 | 26 | 28 | 16 | 5 | 1 250 | 50 | 34 | + | + | 0 | 0 | 0 |
| 243 | 97 | 103 | 75 | 147 | 52 | 54 | 41 | 0 | 0 | 1 | 40 | 96 | 45 | 49 | 34 | 17 | 6 | 1 250 | 65 | 56 | 0 | + | 0 | 0 | 0 |
| 269 | 108 | 93 | 80 | 170 | 44 | 49 | 42 | 0 | 0 | 1 | 40 | 100 | 64 | 44 | 38 | 18 | 9 | 2 250 | 150 | 94 | + | + | 0 | 0 | 0 |
| 206 | 105 | 95 | 83 | 135 | 59 | 48 | 40 | 23 | 0 | 0 | 38 | 71 | 46 | 47 | 43 | 17 | 10 | 3 500 | 142 | 135 | 0 | + | 0 | 0 | 0 |
| 116 | 118 | 101 | 87 | 96 | 68 | 42 | 37 | 10 | 0 | 0 | 34 | 20 | 50 | 59 | 50 | 12 | 10 | 21 000 | 275 | 145 | + | + | 0 | 0 | 0 |
| 156 | 109 | 102 | 87 | 104 | 52 | 40 | 27 | 4 | 0 | 0 | 24 | 52 | 57 | 62 | 60 | 13 | 10 | 6 250 | 90 | 125 | + | + | 0 | 0 | 0 |
| 152 | 103 | 92 | 80 | 108 | 53 | 43 | 26 | 1 | 0 | 0 | 30 | 43 | 50 | 49 | 54 | 12 | 7 | 6 250 | 45 | 100 | + | + | 0 | 0 | 0 |
| 173 | 110 | 92 | 82 | 125 | 48 | 42 | 28 | 0 | 0 | 0 | 26 | 48 | 62 | 50 | 54 | 14 | 8 | 6 875 | — | 63 | + | + | 0 | 0 | 0 |
| 196 | 113 | 99 | 87 | 136 | 47 | 41 | 30 | 0 | 0 | 0 | 28 | 60 | 66 | 58 | 57 | 16 | 7 | 3 100 | 60 | 22 | + | + | 0 | 0 | 0 |
| 173 | 111 | 105 | 91 | 117 | 54 | 42 | 29 | 8 | 0 | 0 | 26 | 56 | 56 | 63 | 62 | 13 | 8 | 3 250 | 27 | 32 | + | + | 0 | 0 | 0 |
| 170 | 94 | 100 | 94 | 117 | 61 | 46 | 30 | 0 | 0 | 0 | 28 | 53 | 34 | 54 | 64 | 12 | 8 | 3 500 | 48 | 23 | + | + | 0 | 0 | 0 |
| 180 | 98 | 91 | 85 | 122 | 59 | 49 | 34 | 0 | 0 | 2 | 48 | 58 | 39 | 42 | 50 | 11 | 7 | 2 000 | 50 | 26 | 0 | + | 0 | 0 | 0 |
| 190 | 98 | 88 | 74 | 127 | 57 | 52 | 39 | 0 | 0 | 1 | 38 | 62 | 42 | 36 | 35 | 14 | 8 | 1 150 | 60 | 37 | + | 0 | 0 | 0 | 0 |
| 214 | 112 | 98 | 81 | 136 | 53 | 52 | 41 | 0 | 0 | 1 | 40 | 78 | 59 | 46 | 40 | 15 | 9 | 1 150 | 35 | 30 | 0 | + | 0 | 0 | 0 |
| 218 | 107 | 103 | 91 | 145 | 51 | 50 | 44 | 0 | 0 | 0 | 32 | 72 | 56 | 52 | 47 | 16 | 9 | 1 350 | 55 | 25 | 0 | + | 0 | 0 | 0 |
| 222 | 114 | 112 | 99 | 147 | 50 | 53 | 42 | 0 | 0 | 0 | 32 | 75 | 64 | 60 | 57 | 13 | 8 | 2 375 | 75 | 45 | 0 | + | 0 | 0 | 0 |
| 236 | 115 | 114 | 104 | 156 | 49 | 52 | 43 | 0 | 0 | 0 | 30 | 80 | 66 | 62 | 61 | 17 | 10 | 900 | 50 | 34 | 0 | + | 0 | 0 | 0 |
| 237 | 105 | 109 | 103 | 155 | 49 | 48 | 45 | 0 | 0 | 0 | 26 | 82 | 56 | 61 | 63 | 16 | 9 | 850 | 100 | 40 | 0 | 0 | 0 | 0 | 0 |
| 248 | 99 | 105 | 99 | 158 | 50 | 51 | 45 | 0 | 0 | 0 | 30 | 90 | 50 | 54 | 54 | 16 | 9 | 1 075 | 125 | 65 | 0 | + | 0 | 0 | 0 |
| 246 | 105 | 108 | 101 | 159 | 53 | 49 | 45 | 0 | 0 | 0 | 32 | 87 | 52 | 58 | 55 | 16 | 10 | 1 875 | 250 | 85 | + | + | 0 | 0 | 0 |
| 252 | 110 | 101 | 101 | 163 | 50 | 51 | 43 | 0 | 0 | 0 | 34 | 90 | 59 | 50 | 58 | 18 | 10 | 1 125 | 300 | 100 | + | + | 0 | 0 | 0 |
| 247 | 96 | 99 | 86 | 159 | 49 | 48 | 41 | 0 | 0 | 0 | 34 | 89 | 47 | 52 | 46 | 16 | 8 | 12 500 | 1 000 | 235 | + | + | 0 | 0 | 0 |
| 260 | 105 | 102 | 94 | 166 | 40 | 44 | 41 | 0 | 0 | 0 | 34 | 94 | 65 | 58 | 53 | 18 | 10 | 3 000 | — | 250 | + | 0 | 0 | 0 | 0 |
| 257 | 100 | 92 | 92 | 168 | 42 | 37 | 36 | 0 | 0 | 0 | 26 | 89 | 58 | 54 | 56 | 20 | 8 | 7 800 | — | 1 250 | 0 | + | 0 | 0 | + |
| 275 | 98 | 93 | 85 | 178 | 50 | 42 | 33 | 0 | 0 | 0 | 22 | 97 | 48 | 51 | 52 | 23 | 7 | 2 600 | 25 | 30 | + | + | 0 | 0 | 0 |
| 239 | 87 | 81 | 90 | 151 | 42 | 37 | 35 | 2 | 0 | 0 | 20 | 88 | 45 | 44 | 54 | 19 | 9 | 7 000 | 1 000 | 185 | + | + | 0 | 0 | + |
| 182 | 78 | 80 | 80 | 120 | 51 | 43 | 32 | 5 | 3 | 0 | 26 | 62 | 27 | 36 | 48 | 14 | 7 | 7 500 | 350 | 210 | 0 | + | 0 | 0 | 0 |
| 171 | 104 | 83 | 59 | 121 | 42 | 41 | 30 | 4 | 0 | 2 | 32 | 50 | 62 | 43 | 59 | 14 | 7 | 3 000 | 300 | 110 | + | 0 | 0 | 0 | 0 |
| 211 | 102 | 96 | 85 | 139 | 52 | 47 | 37 | 2 | 0.1 | 0.4 | 32 | 72 | 50 | 49 | 49 | 15 | 8 | 3 952 | 180 | 121 | .... | .... | .... | .... | ..... |

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12—WATER PURIFICATION WORKS.—(*Continued.*)

| Day of Month. | Temperature of air, in degrees Fahr. | Temperature of water, in degrees Fahr. | Rainfall, in inches. | Volume of Water. | | Filter Data. | | | | | Applied Chemicals. | | | | | | Color. | | Turbidity. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Pounds. | | | Grains per gallon. | | | | | | | | |
| | | | | Pumped, million gal. | Filtered, million gal. | Number used. | Hours in service, average. | Loss of head, maximum, in feet. | Wash-water, percentage. | Use of air. | Lime. | Soda ash. | Coagulant. | Lime. | Soda ash. | Coagulant. | River water. | Filtered water. | River water. | Settled water. | Filtered water. | Free carbonic acid, river water. |
| 1 | 76 | 77 | 0.00 | 14.6 | 14.3 | 10 | 20.2 | 5.2 | 3.2 | 0 | 13 148 | 0 | 5 460 | 6.3 | 0 | 2.6 | 60 | 15 | 121 | 5 | 0 | 3 |
| 2 | 77 | 77 | 0.00 | 14.6 | 14.7 | 9 | 21.5 | 6.1 | 3.1 | 0 | 13 566 | 1 740 | 3 366 | 6.5 | 0.8 | 1.6 | 70 | 15 | 92 | 5 | 0 | 3 |
| 3 | 70 | 77 | tr. | 15.0 | 13.9 | 9 | 20.5 | 6.1 | 2.9 | 0 | 13 756 | 2 805 | 2 800 | 6.4 | 1.3 | 1.3 | 60 | 18 | 67 | 5 | 0 | 3 |
| 4 | 67 | 73 | 0.00 | 12.7 | 11.8 | 9 | 16.2 | 6.1 | 3.4 | 0 | 12 464 | 1 419 | 2 218 | 6.9 | 0.8 | 1.2 | 60 | 21 | 50 | 5 | 0 | 3 |
| 5 | 67 | 73 | 0.09 | 12.3 | 11.8 | 9 | 17.4 | 5.0 | 1.9 | 0 | 11 493 | 1 384 | 2 004 | 6.5 | 0.8 | 1.1 | 62 | 18 | 42 | 5 | 0 | 2 |
| 6 | 65 | 69 | 0.01 | 13.5 | 13.0 | 9 | 21.2 | 5.2 | 2.2 | 0 | 13 680 | 1 568 | 2 124 | 7.1 | 0.8 | 1.1 | 56 | 19 | 41 | 5 | 0 | 2 |
| 7 | 72 | 74 | 0.00 | 14.0 | 14.0 | 9 | 21.0 | 4.9 | 2.5 | 0 | 15 647 | 1 664 | 2 148 | 7.8 | 0.8 | 1.1 | 57 | 22 | 36 | 5 | 0 | 3 |
| 8 | 71 | 74 | 0.00 | 15.1 | 13.8 | 9 | 21.9 | 5.0 | 1.7 | 0 | 16 997 | 1 768 | 2 352 | 7.9 | 0.8 | 1.1 | 47 | 17 | 37 | 5 | 0 | 3 |
| 9 | 73 | 75 | 0.00 | 16.3 | 14.6 | 9 | 22.8 | 5.4 | 1.6 | 0 | 18 502 | 1 912 | 2 176 | 7.9 | 0.8 | 0.9 | 50 | 15 | 28 | 5 | 0 | 3 |
| 10 | 76 | 76 | 0.00 | 14.9 | 14.5 | 9 | 23.0 | 5.0 | 1.5 | 0 | 16 895 | 1 760 | 2 120 | 7.9 | 0.8 | 1.0 | 49 | 15 | 28 | 5 | 0 | 3 |
| 11 | 75 | 76 | 0.16 | 13.0 | 11.8 | 9 | 18.7 | 4.9 | 3.4 | 0 | 13 817 | 1 528 | 1 576 | 7.4 | 0.8 | 0.8 | 45 | 17 | 28 | 5 | 0 | 3 |
| 12 | 77 | 76 | 1.11 | 14.3 | 13.5 | 9 | 20.5 | 4.5 | 2.9 | 0 | 15 356 | 1 600 | 1 600 | 7.5 | 0.8 | 0.8 | 45 | 17 | 26 | 5 | 0 | 3 |
| 13 | 74 | 76 | 0.38 | 15.0 | 13.7 | 9 | 19.5 | 3.5 | 4.9 | 0 | 17 453 | 1 800 | 1 744 | 8.1 | 0.8 | 0.8 | 38 | 15 | 36 | 5 | 0 | 2 |
| 14 | 74 | 76 | tr. | 15.1 | 14.1 | 9 | 20.3 | 2.8 | 2.8 | 0 | 17 746 | 1 768 | 1 648 | 8.2 | 0.8 | 0.8 | 40 | 7 | 25 | 5 | 0 | 3 |
| 15 | 78 | 78 | 0.57 | 14.0 | 14.6 | 9 | 18.4 | 2.9 | 2.4 | 0 | 16 530 | 1 648 | 1 720 | 8.3 | 0.8 | 0.9 | 44 | 4 | 20 | 5 | 0 | 2 |
| 16 | 72 | 77 | 0.23 | 13.7 | 13.4 | 9 | 20.2 | 3.2 | 5.1 | 0 | 15 162 | 1 720 | 2 016 | 7.7 | 0.9 | 1.0 | 40 | 6 | 30 | 5 | 0 | 2 |
| 17 | 67 | 73 | 0.00 | 13.8 | 14.3 | 9 | 21.9 | 3.5 | 3.9 | 0 | 14 573 | 1 640 | 2 568 | 7.4 | 0.8 | 1.3 | 42 | 5 | 182 | 7 | 0 | 4 |
| 18 | 67 | 71 | 0.01 | 13.5 | 12.1 | 9 | 21.5 | 4.2 | 5.7 | 0 | 9 908 | 624 | 6 419 | 5.1 | 0.3 | 3.3 | 50 | 5 | 309 | 20 | 0 | 3 |
| 19 | 64 | 71 | 0.00 | 14.7 | 14.6 | 10 | 18.5 | 4.9 | 5.2 | 0 | 11 458 | 0 | 8 022 | 5.5 | 0 | 3.8 | 50 | 10 | 314 | 20 | 0 | 4 |
| 20 | 68 | 72 | 0.00 | 14.3 | 14.0 | 9 | 19.2 | 3.0 | 2.0 | 0 | 11 485 | 0 | 8 169 | 5.6 | 0 | 4.0 | 50 | 12 | 256 | 15 | 0 | 3 |
| 21 | 74 | 74 | 0.00 | 14.0 | 13.8 | 9 | 19.2 | 3.1 | 2.4 | 0 | 11 257 | 0 | 6 634 | 5.6 | 0 | 3.3 | 55 | 12 | 182 | 15 | 0 | 3 |
| 22 | 72 | 73 | 0.40 | 14.2 | 13.4 | 9 | 19.3 | 3.0 | 3.9 | 0 | 12 184 | 0 | 5 456 | 6.0 | 0 | 2.7 | 67 | 11 | 142 | 18 | 0 | 3 |
| 23 | 66 | 70 | 0.03 | 13.8 | 13.5 | 9 | 18.8 | 2.7 | 2.2 | 0 | 11 443 | 0 | 6 176 | 5.8 | 0 | 3.1 | 67 | 11 | 108 | 20 | 0 | 3 |
| 24 | 68 | 69 | 0.00 | 14.4 | 13.8 | 9 | 19.1 | 3.1 | 2.4 | 0 | 12 013 | 0 | 6 592 | 5.8 | 0 | 3.2 | 65 | 12 | 91 | 18 | 0 | 3 |
| 25 | 69 | 72 | 0.00 | 11.9 | 11.4 | 9 | 15.5 | 3.3 | 3.5 | 0 | 10 673 | 0 | 5 108 | 6.3 | 0 | 3.0 | 64 | 12 | 74 | 15 | 0 | 4 |
| 26 | 70 | 74 | 0.02 | 13.9 | 13.6 | 9 | 19.2 | 2.7 | 3.0 | 0 | 12 611 | 0 | 4 300 | 6.3 | 0 | 2.2 | 57 | 14 | 57 | 12 | 0 | 3 |
| 27 | 71 | 75 | 0.02 | 13.4 | 13.1 | 9 | 18.7 | 2.7 | 2.6 | 0 | 11 985 | 0 | 3 136 | 6.3 | 0 | 1.6 | 61 | 12 | 55 | 15 | 0 | 3 |
| 28 | 76 | 75 | 0.00 | 14.5 | 14.1 | 9 | 20.0 | 3.0 | 4.3 | 0 | 12 511 | 0 | 3 320 | 6.0 | 0 | 1.6 | 57 | 13 | 52 | 10 | 0 | 4 |
| 29 | 77 | 78 | 0.08 | 14.3 | 13.9 | 9 | 20.2 | 2.4 | 4.5 | 0 | 13 024 | 0 | 3 048 | 5.4 | 0 | 1.5 | 52 | 12 | 44 | 10 | 0 | 3 |
| 30 | 74 | 77 | 0.18 | 15.3 | 13.8 | 9 | 19.0 | 2.6 | 3.8 | 0 | 15 459 | 0 | 3 088 | 7.1 | 0 | 1.4 | 57 | 14 | 39 | 12 | 0 | 4 |
| 31 | 73 | 77 | tr. | 13.7 | 13.5 | 9 | 18.9 | 2.8 | 3.1 | 0 | 13 919 | 0 | 2 422 | 7.1 | 0 | 1.2 | 52 | 14 | 39 | 10 | 0 | 3 |
| Av. | 72 | 74 | .... | 14.1 | 13.6 | 9 | 19.8 | 4.0 | 3.2 | .. | 13 765 | 914 | 3 598 | 6.8 | 0.4 | 1.8 | 54 | 13 | 86 | 10 | 0 | 3 |

\+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for July, 1909.

| Analytical Results, in Parts per Million. | | | | | | | | | | | | | | | | | | | | Bacteriological Tests. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total hardness. | | | | Total alkalinity. | | | | Caustic alk. | | | Mono. carb. alk., filtered water. | Incrustants. | | | | Magnesium. | | Bacteria per c. c. | | | Presumptive *Coli* tests. | | | | | |
| | | | | | | | | | | | | | | | | | | | | | River water. | | | | | |
| | | | | | | | | | | | | | | | | | | | | | 1 c. c. | | | 1 c. c. | | 50 c. c. |
| River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | Inlet to sett. basin. | Settled water. | Filtered water. | | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Filtered water. | River water. | Settled water. | Filtered water. | Smith method. | Bile method. | Smith method. | Bile method. | Smith method. | |
| 176 | 100 | 101 | 78 | 125 | 40 | 39 | 28 | 0 | 1 | 0 | 26 | 51 | 60 | 61 | 50 | 13 | 7 | 1 000 | 42 | 46 | + | + | 0 | 0 | — | |
| 189 | 93 | 104 | 93 | 129 | 43 | 39 | 26 | 7 | 1 | 0 | 24 | 60 | 50 | 65 | 67 | 15 | 9 | 1 800 | 35 | 15 | + | + | 0 | 0 | — | |
| 188 | 83 | 92 | 86 | 132 | 50 | 44 | 29 | 2 | 4 | 0 | 28 | 57 | 33 | 48 | 57 | 15 | 7 | 1 250 | 42 | 8 | 0 | 0 | 0 | 0 | — | |
| 192 | 94 | 85 | 72 | 138 | 46 | 48 | 34 | 4 | 2 | 0 | 34 | 54 | 48 | 37 | 37 | 15 | 7 | | 700 | 42 | 6 | + | + | 0 | 0 | — | |
| 190 | 98 | 90 | 74 | 143 | 50 | 45 | 34 | 0 | 1 | 0 | 34 | 56 | 47 | 45 | 40 | 18 | 7 | | 550 | 33 | 6 | + | + | 0 | 0 | — | |
| 199 | 94 | 87 | 81 | 145 | 48 | 46 | 36 | 2 | 0 | 0 | 34 | 54 | 46 | 41 | 45 | 16 | 9 | | 750 | 32 | 20 | 0 | 0 | 0 | 0 | 0 |
| 213 | 100 | 88 | 80 | 155 | 47 | 47 | 37 | 0 | 0 | 0 | 34 | 59 | 53 | 41 | 43 | 16 | 8 | | 650 | 37 | 8 | 0 | + | 0 | 0 | — |
| 218 | 95 | 95 | 86 | 154 | 45 | 44 | 36 | 3 | 0 | 0 | 34 | 63 | 50 | 51 | 50 | 15 | 8 | 1 | 000 | 30 | 12 | + | + | 0 | 0 | — |
| 223 | 94 | 91 | 84 | 161 | 45 | 43 | 35 | 1 | 0 | 1 | 34 | 62 | 49 | 48 | 48 | 18 | 10 | 1 | 000 | 50 | 22 | + | + | 0 | 0 | — |
| 228 | 98 | 99 | 90 | 160 | 43 | 42 | 34 | 3 | 2 | 2 | 32 | 68 | 56 | 57 | 56 | 16 | 8 | | 825 | 70 | 12 | + | + | 0 | 0 | — |
| 230 | 102 | 87 | 88 | 166 | 47 | 42 | 34 | 0 | 0 | 1 | 34 | 64 | 54 | 55 | 53 | 16 | 8 | | 450 | 25 | 3 | 0 | + | 0 | 0 | — |
| 238 | 98 | 85 | 88 | 171 | 45 | 44 | 36 | 0 | 0 | 0 | 32 | 67 | 53 | 41 | 52 | 18 | 10 | 4 | 450 | 42 | 10 | + | + | 0 | 0 | — |
| 244 | 103 | 98 | 91 | 177 | 44 | 42 | 38 | 0 | 0 | 0 | 30 | 67 | 59 | 56 | 52 | 19 | 9 | 3 | 000 | 85 | 44 | + | + | 0 | 0 | — |
| 254 | 100 | 98 | 92 | 177 | 42 | 40 | 37 | 0 | 0 | 0 | 30 | 77 | 58 | 58 | 55 | 19 | 9 | 1 | 100 | 18 | 2 | + | + | 0 | 0 | — |
| 249 | 106 | 104 | 96 | 181 | 42 | 38 | 36 | 0 | 0 | 0 | 32 | 68 | 64 | 66 | 60 | 19 | 10 | 1 | 000 | 31 | 4 | + | + | 0 | 0 | — |
| 242 | 96 | 96 | 87 | 176 | 40 | 40 | 34 | 2 | 0 | 0 | 34 | 66 | 56 | 56 | 53 | 20 | 11 | 1 | 050 | 23 | 2 | + | + | 0 | 0 | — |
| 241 | 112 | 100 | 91 | 165 | 41 | 40 | 33 | 0 | 0 | 0 | 32 | 76 | 71 | 60 | 57 | 21 | 10 | 34 | 400 | 52 | 5 | + | + | 0 | 0 | 0 |
| 136 | 96 | 98 | 93 | 90 | 50 | 44 | 33 | 0 | 0 | 0 | 30 | 46 | 46 | 54 | 58 | 11 | 11 | 30 | 000 | 115 | 15 | + | + | 0 | 0 | 0 |
| 136 | 87 | 92 | 90 | 91 | 31 | 36 | 30 | 0 | 0 | 0 | 28 | 35 | 56 | 56 | 60 | 11 | 8 | 10 | 000 | 68 | 30 | + | + | 0 | 0 | 0 |
| 138 | 81 | 82 | 86 | 98 | 30 | 26 | 26 | 0 | 0 | 0 | 16 | 35 | 51 | 57 | 60 | 11 | 7 | 9 | 400 | 40 | 23 | + | + | 0 | 0 | 0 |
| 144 | 83 | 79 | 81 | 105 | 28 | 23 | 24 | 0 | 0 | 0 | 10 | 39 | 55 | 56 | 57 | 10 | 7 | 3 | 150 | 50 | 21 | + | + | 0 | 0 | 0 |
| 150 | 91 | 86 | 82 | 112 | 40 | 28 | 22 | 0 | 0 | 0 | 10 | 38 | 51 | 58 | 59 | 13 | 6 | 2 | 600 | 50 | 25 | + | + | 0 | 0 | 0 |
| 152 | 87 | 81 | 80 | 114 | 41 | 30 | 28 | 9 | 0 | 0 | 20 | 38 | 46 | 51 | 52 | 13 | 8 | 2 | 100 | 44 | 12 | + | + | 0 | 0 | — |
| 156 | 88 | 87 | 85 | 116 | 41 | 33 | 29 | 0 | 0 | 0 | 22 | 39 | 47 | 54 | 54 | 12 | 7 | 1 | 800 | 42 | 10 | + | + | 0 | 0 | — |
| 161 | 86 | 86 | 82 | 120 | 39 | 32 | 30 | 0 | 0 | 0 | 22 | 42 | 47 | 55 | 52 | 11 | 7 | 1 | 200 | 20 | 8 | + | + | 0 | 0 | — |
| 161 | 89 | 89 | 88 | 124 | 39 | 33 | 29 | 1 | 0 | 0 | 22 | 38 | 49 | 56 | 59 | 11 | 7 | 1 | 200 | 25 | 2 | + | + | 0 | 0 | — |
| 176 | 91 | 95 | 90 | 130 | 41 | 33 | 29 | 1 | 0 | 0 | 24 | 46 | 50 | 62 | 61 | 14 | 7 | 1 | 400 | 36 | 8 | + | + | 0 | 0 | — |
| 178 | 92 | 92 | 86 | 134 | 41 | 37 | 29 | 0 | 0 | 0 | 26 | 43 | 51 | 55 | 56 | 12 | 7 | 1 | 300 | 25 | 10 | — | + | 0 | 0 | — |
| 177 | 93 | 88 | 85 | 136 | 41 | 37 | 31 | 0 | 0 | 0 | 28 | 42 | 52 | 52 | 54 | 15 | 7 | 1 | 200 | 27 | 5 | + | — | 0 | 0 | — |
| 192 | 97 | 91 | 86 | 143 | 41 | 35 | 32 | 0 | 0 | 0 | 26 | 49 | 56 | 56 | 54 | 14 | 8 | 1 | 860 | 35 | 8 | + | + | — | — | — |
| 181 | 97 | 94 | 85 | 143 | 42 | 37 | 32 | 12 | 0 | 0 | 28 | 49 | 55 | 58 | 53 | 13 | 8 | 2 | 100 | 46 | 4 | + | + | — | — | — |
| 192 | 94 | 92 | 86 | 139 | 42 | 38 | 32 | 2 | 0.4 | 0.1 | 27 | 53 | 52 | 54 | 54 | 15 | 8 | 4 | 009 | 42 | 13 | .... | .... | .... | .... | ..... |

Coagulant = Sulphate of iron or sulphate of alumina.

TABLE 12.—WATER PURIFICATION WORKS—(*Continued.*)

| Day of Month. | Temperature of air, in degrees Fahr. | Temperature of water, in degrees Fahr. | Rainfall, in inches. | Volume of Water. | | Filter Data. | | | | | Applied Chemicals. | | | | | | Color. | | Turbidity. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Pumped, million gal. | Filtered, million gal. | Number used. | Hours in service, average. | Loss of head, maximum, in feet. | Wash-water, percentage. | Use of air. | Pounds. | | | Grains per gallon. | | | River water. | Filtered water. | River water. | Settled water. | Filtered water. | Free carbonic acid, river water. |
| | | | | | | | | | | | Lime. | Soda ash. | Coagulant. | Lime. | Soda ash. | Coagulant. | | | | | | |
| 1 | 76 | 75 | 0.00 | 12.5 | 11.8 | 9 | 16.5 | 2.8 | 2.2 | 0 | 12 124 | 0 | 1 884 | 6.8 | 0.0 | 1.1 | 46 | 9 | 28 | 7 | 0 | 3 |
| 2 | 75 | 77 | 0.00 | 13.9 | 14.6 | 9 | 19.6 | 3.2 | 2.9 | 0 | 12 569 | 0 | 1 878 | 6.3 | 0.0 | 0.9 | 45 | 11 | 35 | 8 | 0 | 3 |
| 3 | 76 | 77 | 0.00 | 17.0 | 14.3 | 8 | 19.9 | 3.7 | 2.8 | 0 | 15 065 | 0 | 1 860 | 6.3 | 0.0 | 0.8 | 45 | 10 | 32 | 5 | 0 | 3 |
| 4 | 72 | 76 | 0.00 | 16.0 | 14.4 | 8 | 20.3 | 4.2 | 2.8 | 0 | 14 825 | 0 | 1 548 | 6.5 | 0.0 | 0.7 | 44 | 12 | 36 | 5 | 0 | 3 |
| 5 | 73 | 76 | 0.02 | 15.4 | 13.6 | 9 | 17.6 | 4.5 | 3.4 | 0 | 14 775 | 0 | 1 886 | 6.7 | 0.0 | 0.6 | 36 | 9 | 24 | 3 | 0 | 3 |
| 6 | 71 | 74 | 0.00 | 13.5 | 14.0 | 9 | 16.8 | 4.0 | 2.4 | 0 | 13 714 | 0 | 1 248 | 7.1 | 0.0 | 0.6 | 28 | 8 | 22 | 3 | 0 | 3 |
| 7 | 71 | 74 | 0.00 | 15.9 | 15.0 | 9 | 19.8 | 3.0 | 2.7 | 0 | 16 262 | 0 | 1 350 | 7.2 | 0.0 | 0.6 | 26 | 11 | 22 | 3 | 0 | 3 |
| 8 | 74 | 76 | 0.00 | 13.0 | 12.3 | 9 | 16.8 | 2.3 | 2.5 | 0 | 13 629 | 0 | 1 356 | 7.3 | 0.0 | 0.7 | 27 | 8 | 22 | 3 | 0 | 3 |
| 9 | 82 | 77 | 0.00 | 15.1 | 15.8 | 9 | 22.6 | 3.0 | 2.2 | 0 | 15 578 | 0 | 1 794 | 7.2 | 0.0 | 0.8 | 24 | 9 | 21 | 1 | 0 | 3 |
| 10 | 75 | 78 | 0.09 | 16.8 | 15.0 | 9 | 23.4 | 4.3 | 3.8 | 0 | 17 510 | 1 131 | 1 878 | 7.3 | 0.5 | 0.8 | 25 | 9 | 22 | 1 | 0 | 3 |
| 11 | — | — | 0.00 | 15.5 | 15.1 | 9 | 22.7 | 3.0 | 3.7 | 0 | 15 784 | 1 693 | 1 740 | 7.1 | 0.8 | 0.8 | 22 | 5 | 21 | 3 | 0 | 3 |
| 12 | 68 | 75 | 0.15 | 15.1 | 13.7 | 9 | 21.2 | 2.9 | 3.5 | 0 | 15 817 | 1 776 | 1 872 | 7.3 | 0.8 | 0.9 | 22 | 3 | 20 | 2 | 0 | 3 |
| 13 | 72 | 73 | 0.00 | 14.6 | 14.8 | 8 | 23.0 | 3.2 | 4.7 | 0 | 15 014 | 1 656 | 1 842 | 7.2 | 0.8 | 0.9 | 19 | 3 | 20 | 1 | 0 | 3 |
| 14 | 77 | 75 | 0.23 | 15.7 | 14.7 | 8 | 23.0 | 3.9 | 3.9 | 0 | 16 211 | 1 904 | 1 974 | 7.2 | 0.8 | 0.9 | 19 | 2 | 21 | 2 | 0 | 4 |
| 15 | 72 | 76 | 1.69 | 13.0 | 11.9 | 8 | 19.1 | 3.6 | 3.7 | 0 | 14 089 | 1 632 | 2 373 | 7.6 | 0.9 | 1.3 | 30 | 3 | 23 | 2 | 0 | 3 |
| 16 | 74 | 73 | 0.14 | 14.5 | 14.5 | 9 | 19.2 | 4.4 | 4.0 | 0 | 15 869 | 1 640 | 4 364 | 7.7 | 0.8 | 2.1 | 26 | 3 | 47 | 3 | 0 | 4 |
| 17 | 70 | 76 | tr. | 15.4 | 14.2 | 9 | 19.9 | 3.6 | 3.5 | 0 | 18 671 | 1 728 | 3 423 | 8.5 | 0.8 | 1.6 | 22 | 3 | 30 | 3 | 0 | 3 |
| 18 | 68 | 75 | 0.00 | 14.5 | 14.0 | 9 | 20.0 | 4.1 | 3.3 | 0 | 17 188 | 1 772 | 2 920 | 8.3 | 0.9 | 1.4 | 25 | 3 | 22 | 3 | 0 | 4 |
| 19 | 71 | 74 | 0.00 | 14.3 | 14.3 | 9 | 19.8 | 3.5 | 3.2 | 0 | 16 473 | 1 788 | 2 600 | 8.1 | 0.9 | 1.3 | 31 | 2 | 23 | 3 | 0 | 4 |
| 20 | 73 | 74 | 0.00 | 15.5 | 14.3 | 9 | 19.3 | 3.7 | 3.2 | 0 | 18 753 | 2 304 | 2 480 | 8.5 | 1.0 | 1.1 | 25 | 2 | 23 | 3 | 0 | 4 |
| 21 | 67 | 72 | 0.00 | 16.6 | 14.5 | 9 | 21.0 | 4.7 | 2.8 | 0 | 18 905 | 2 496 | 1 772 | 8.0 | 1.1 | 0.7 | 29 | 4 | 23 | 3 | 0 | 4 |
| 22 | 65 | 71 | 0.00 | 13.7 | 12.5 | 9 | 17.4 | 4.2 | 3.6 | 0 | 14 096 | 2 048 | 1 132 | 7.2 | 1.0 | 0.6 | 30 | 3 | 22 | 2 | 0 | 3 |
| 23 | 62 | 70 | 0.00 | 16.6 | 15.1 | 9 | 20.1 | 4.5 | 2.7 | 0 | 14 586 | 2 512 | 1 288 | 6.1 | 1.1 | 0.5 | 32 | 3 | 21 | 2 | 0 | 4 |
| 24 | 72 | 71 | 0.00 | 16.9 | 15.1 | 9 | 21.2 | 4.2 | 2.7 | 0 | 15 305 | 2 536 | 1 284 | 6.3 | 1.0 | 0.5 | 32 | 7 | 20 | 2 | 0 | 5 |
| 25 | 75 | 74 | 0.05 | 16.1 | 15.3 | 9 | 21.3 | 4.1 | 3.3 | 0 | 13 754 | 956 | 1 264 | 6.0 | 0.4 | 0.5 | 36 | 12 | 20 | 3 | 0 | 4 |
| 26 | 78 | 76 | 0.04 | 15.6 | 15.0 | 9 | 20.2 | 4.4 | 4.8 | 0 | 12 098 | 0 | 1 228 | 5.4 | 0.0 | 0.6 | 37 | 11 | 20 | 5 | 0 | 3 |
| 27 | 80 | 80 | 0.09 | 17.1 | 15.7 | 9 | 22.2 | 4.6 | 3.1 | 0 | 14 464 | 464 | 1 352 | 5.9 | 0.2 | 0.6 | 32 | 11 | 20 | 10 | 0 | 3 |
| 28 | 79 | 81 | 0.02 | 17.6 | 15.2 | 9 | 20.4 | 6.4 | 4.3 | 0 | 11 611 | 2 012 | 1 344 | 4.6 | 0.8 | 0.5 | 39 | 14 | 22 | 7 | 0 | 1 |
| 29 | 74 | 80 | 0.01 | 14.2 | 12.8 | 9 | 17.3 | 8.0 | 5.0 | 0 | 8 991 | 1 720 | 1 164 | 4.4 | 0.8 | 0.6 | 37 | 12 | 22 | 6 | 0 | 0 |
| 30 | 66 | 75 | 0.00 | 15.5 | 15.4 | 9 | 20.9 | 7.9 | 3.2 | 0 | 11 436 | 1 768 | 1 212 | 5.2 | 0.8 | 0.5 | 37 | 15 | 20 | 5 | 0 | 2 |
| 31 | 65 | 73 | 0.00 | 16.3 | 15.5 | 8 | 23.3 | 7.9 | 3.0 | 0 | 12 708 | 1 904 | 1 288 | 5.5 | 0.8 | 0.6 | 38 | 17 | 20 | 5 | 0 | 3 |
| Av. | 72 | 75 | .... | 15.2 | 14.3 | 9 | 20.2 | 4.3 | 3.3 | .. | 14 767 | 1 208 | 1 810 | 6.8 | 0.5 | 0.8 | 31 | 8 | 24 | 4 | 0 | 3 |

+ = Present. 0 = Not present. — = Not tested.

—Records of Operation for August, 1909.

| Analytical Results, in Parts per Million. | | | | | | | | | | | | | | | | | | | Bacteriological Tests. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total hardness. | | | | Total alkalinity. | | | | Caustic alk. | | | Mono. carb. alk., filtered water. | Incrustants. | | | | Magnesium. | | Bacteria per c. c. | | | Presumptive *Coli* tests. | | | | | |
| | | | | | | | | | | | | | | | | | | | | | River water. | | | Filtered water. | | |
| | | | | | | | | | | | | | | | | | | | | | 1 c. c. | | | 1 c. c. | | 50 c.c. |
| River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | Inlet to sett. basin. | Settled water. | Filtered water. | | River water. | Inlet to sett. basin. | Settled water. | Filtered water. | River water. | Filtered water. | River water. | Settled water. | Filtered water. | Smith method. | Bile method. | Smith method. | Bile method. | Smith method. | |
| 190 | 92 | 95 | 87 | 144 | 40 | 40 | 31 | 3 | 1 | 1 | 30 | 46 | 52 | 55 | 55 | 15 | 8 | 2 530 | 43 | 6 | ++ | — | 0 | 0 | 0 | |
| 198 | 96 | 84 | 84 | 148 | 42 | 38 | 32 | 8 | 0 | 1 | 32 | 50 | 54 | 46 | 52 | 15 | 7 | 2 400 | 25 | 3 | ++ | + | 0 | 0 | 0 | |
| 200 | 94 | 88 | 85 | 132 | 40 | 37 | 32 | 0 | 0 | 2 | 30 | 48 | 53 | 51 | 54 | 17 | 8 | 1 480 | 21 | 9 | ++ | — | 0 | 0 | 0 | |
| 208 | 97 | 92 | 84 | 154 | 41 | 37 | 34 | 0 | 0 | 0 | 30 | 49 | 56 | 55 | 51 | 16 | 9 | 1 300 | 43 | 19 | ++ | — | — | — | — | |
| 213 | 92 | 91 | 87 | 157 | 39 | 39 | 34 | 0 | 0 | 0 | 30 | 56 | 58 | 52 | 53 | 16 | 10 | 1 200 | 66 | 48 | ++ | — | 0 | 0 | 0 | |
| 220 | 94 | 95 | 86 | 163 | 37 | 39 | 36 | 0 | 0 | 0 | 30 | 58 | 56 | 56 | 49 | 18 | 11 | 1 850 | 43 | 106 | ++ | + | 0 | 0 | 0 | |
| 230 | 106 | 103 | 101 | 166 | 39 | 38 | 37 | 0 | 0 | 0 | 30 | 64 | 67 | 65 | 64 | 18 | 11 | 2 100 | 85 | 113 | 0 | 0 | 0 | 0 | 0 | |
| 226 | 109 | 105 | 96 | 169 | 38 | 39 | 36 | 0 | 0 | 0 | 28 | 67 | 71 | 67 | 69 | 19 | 10 | 1 580 | 44 | 47 | 0 | 0 | 0 | 0 | 0 | |
| 242 | 116 | 108 | 100 | 173 | 42 | 36 | 37 | 0 | 0 | 0 | 26 | 69 | 74 | 67 | 68 | 20 | 10 | 1 000 | 11 | 14 | 0 | 0 | 0 | 0 | 0 | |
| 247 | 108 | 106 | 101 | 173 | 37 | 34 | 35 | 0 | 0 | 0 | 24 | 75 | 71 | 71 | 66 | 21 | 11 | 1 570 | 7 | 5 | ++ | + | 0 | 0 | 0 | |
| 242 | 104 | 103 | 104 | 167 | 39 | 36 | 33 | 0 | 0 | 0 | 26 | 75 | 65 | 67 | 71 | 22 | 11 | 425 | 21 | 4 | ++ | 0 | 0 | 0 | 0 | |
| 237 | 104 | 104 | 99 | 167 | 43 | 39 | 36 | 0 | 0 | 0 | 24 | 70 | 62 | 65 | 64 | 21 | 11 | 2 000 | 22 | 6 | ++ | — | 0 | 0 | 0 | |
| 248 | 107 | 105 | 99 | 172 | 45 | 43 | 37 | 0 | 0 | 0 | 28 | 76 | 62 | 63 | 62 | 20 | 11 | 1 600 | 20 | 12 | — | — | 0 | 0 | 0 | |
| 245 | 108 | 111 | 101 | 170 | 47 | 46 | 38 | 0 | 0 | 0 | 28 | 75 | 61 | 65 | 63 | 21 | 12 | 900 | 16 | 2 | 0 | 0 | 0 | 0 | 0 | |
| 226 | 110 | 107 | 105 | 163 | 41 | 43 | 39 | 0 | 0 | 0 | 24 | 73 | 69 | 64 | 67 | 20 | 12 | 7 800 | 20 | 2 | ++ | + | 0 | 0 | 0 | |
| 222 | 96 | 98 | 99 | 159 | 36 | 41 | 38 | 3 | 0 | 0 | 26 | 63 | 60 | 57 | 61 | 19 | 12 | 9 000 | 50 | 5 | ++ | + | 0 | 0 | 0 | |
| 241 | 97 | 98 | 94 | 168 | 34 | 37 | 34 | 0 | 0 | 0 | 22 | 73 | 64 | 62 | 60 | 20 | 11 | 2 500 | 25 | 15 | ++ | 0 | 0 | 0 | 0 | |
| 244 | 102 | 97 | 92 | 169 | 37 | 35 | 32 | 8 | 0 | 0 | 24 | 75 | 66 | 63 | 59 | 22 | 11 | 1 350 | 65 | 8 | ++ | + | 0 | 0 | 0 | |
| 245 | 100 | 98 | 92 | 172 | 37 | 36 | 28 | 0 | 0 | 0 | 28 | 72 | 63 | 62 | 64 | 21 | 10 | 2 500 | 65 | 22 | 0 | + | 0 | 0 | 0 | |
| 257 | 106 | 101 | 94 | 182 | 46 | 36 | 30 | 4 | 0 | 0 | 26 | 75 | 60 | 66 | 64 | 22 | 10 | 1 600 | 150 | 40 | ++ | ++ | 0 | 0 | 0 | |
| 230 | 96 | 102 | 91 | 163 | 41 | 40 | 30 | 2 | 1 | 0 | 26 | 68 | 55 | 62 | 61 | 21 | 11 | 1 400 | 90 | 45 | ++ | ++ | 0 | 0 | 0 | |
| 217 | 91 | 92 | 85 | 149 | 41 | 38 | 30 | 3 | 3 | 3 | 32 | 67 | 51 | 54 | 55 | 20 | 10 | 1 500 | 45 | 44 | ++ | ++ | 0 | 0 | 0 | |
| 216 | 96 | 94 | 81 | 147 | 47 | 43 | 31 | 8 | 0 | 5 | 26 | 69 | 49 | 50 | 50 | 20 | 9 | 1 300 | 180 | 65 | ++ | ++ | 0 | 0 | 0 | |
| 210 | 92 | 94 | 83 | 147 | 45 | 47 | 36 | 0 | 0 | 0 | 30 | 63 | 46 | 47 | 47 | 18 | 8 | 450 | 2 | 2 | 0 | ++ | 0 | 0 | 0 | |
| 205 | 105 | 95 | 84 | 142 | 57 | 48 | 38 | 0 | 0 | 0 | 30 | 64 | 48 | 47 | 46 | 16 | 10 | 1 600 | 200 | 100 | 0 | 0 | 0 | 0 | 0 | |
| 204 | 106 | 103 | 85 | 140 | 45 | 42 | 35 | 0 | 0 | 0 | 30 | 64 | 61 | 61 | 51 | 16 | 10 | 2 250 | 165 | 40 | ++ | 0 | 0 | 0 | 0 | |
| 204 | 108 | 113 | 100 | 138 | 43 | 43 | 34 | 3 | 0 | 0 | 28 | 66 | 66 | 70 | 66 | 15 | 10 | 700 | — | 35 | ++ | 0 | 0 | 0 | 0 | |
| 182 | 94 | 100 | 92 | 122 | 47 | 44 | 34 | 1 | 0 | 0 | 30 | 60 | 46 | 56 | 58 | 16 | 10 | 800 | 500 | 40 | ++ | 0 | 0 | 0 | 0 | |
| 185 | 106 | 104 | 93 | 118 | 54 | 51 | 35 | 0 | 0 | 0 | 34 | 67 | 51 | 53 | 58 | 15 | 9 | 850 | 300 | 25 | ++ | 0 | 0 | 0 | 0 | |
| 197 | 107 | 97 | 84 | 134 | 57 | 48 | 37 | 0 | 0 | 0 | 34 | 64 | 50 | 48 | 47 | 16 | 10 | 750 | 42 | 31 | ++ | 0 | 0 | 0 | 0 | |
| 197 | 95 | 94 | 91 | 134 | 52 | 48 | 43 | 0 | 0 | 0 | 32 | 63 | 44 | 46 | 48 | 17 | 11 | 250 | 115 | 4 | ++ | 0 | 0 | 0 | 0 | |
| 221 | 101 | 99 | 92 | 156 | 49 | 41 | 35 | 1.4 | 0.2 | 0.3 | 28 | 65 | 58 | 58 | 58 | 19 | 10 | 1 888 | 83 | 29 | .... | .... | .... | .... | ..... | |

Coagulant = Sulphate of iron or sulphate of alumina.

on August 17th, 1908, a partial supply of filtered water was begun, the filtered water being run by gravity to the old West Side Pumping Station and pumped from there. On October 28th, 1908, the old West Side Pumping Station was shut down, the old East Side Pumping Station having been shut down shortly before, and since this date the city has been supplied entirely with filtered water from the new works. Filtration began regularly on August 19th, 1908, and softening on September 22d, 1908.

The principal contracts for the work were:

Water purification works..... Westwater and Casey.
Machinery and equipment..... The Holly Manufacturing Company.
Pumping station and connections.. Westwater and Casey.
Cast-iron force mains..... Westwater and Casey.

## Operation.

The daily records of the results of operation of the water purification works for the eight months, January to August, 1909, inclusive, are presented in Table 12. The writer has not been in charge of operation, his direct connection with the works having ceased on January 1st, 1909, and it is, therefore, through the courtesy of the Engineer and Chief Chemist of the works that he is enabled to present these results. A detailed discussion of the methods of operation and of the results is not within the province of this paper, and, therefore, the writer will not enter into this phase of the subject, but hopes that a full discussion may be presented by those having a direct oversight of the works.

The problem of softening and filtering the Scioto River water is an exceedingly complex one, as the water is subject at times to rapid fluctuations in turbidity, color, alkalinity, and incrustants, and in the portion of magnesia serving as a coagulant. Following heavy rains the turbidity rapidly increases while the hardness correspondingly decreases. Further, some of the turbidity in the settling basins is undoubtedly due to precipitates coming from the applied chemicals.

From an examination of the data in Table 12 it will be seen that the river water is an unusually difficult one to handle. While it may be noted that at times somewhat abnormal results have been obtained, such occasional results are to be expected in a plant passing through its first year of service, especially when treating a water similar to that of the Scioto River in reference to which there

was available a very limited amount of information as to the best method of treating the water under variable conditions, as was the case at Columbus when the works were designed. The bacterial removal, as a rule, has been very satisfactory, but in some instances the numbers in the filtered water have been very high, due to bacterial growths in the settling basins, in the filters, or in both.

While, from the experience obtained during the first year of service, it has been found that for greater ease of operation some few modifications would be desirable, the results obtained demonstrate conclusively that the design of the works is a sound one, and that the works are capable of producing a perfectly satisfactory, softened, purified water, suitable in all respects for public water-supply purposes. The quality of the water furnished from the works has given excellent satisfaction among the water consumers, and has caused the abandonment of a large number of rain-water cisterns throughout the city.

## II.—THE IMPROVED SEWAGE WORKS.

Before describing the sewage works which have recently been completed at Columbus, it will be well to outline briefly the sewerage system of the city and explain the sewage problem which presented itself for solution.

*Sewerage System.*—The topography of Columbus is such that, in the collection of the storm-water and dry-weather sewage, the city is divided naturally into three districts: the East Side Sewer District, the Intercepting Sewer District, and the West Side Sewer District. The outline of these districts is shown on Fig. 1.

The East Side District is sewered on the combined system, with an outlet sewer in East Main Street emptying into Alum Creek, which in turn discharges into the Scioto River a few miles below Columbus.

The Intercepting Sewer District is sewered largely on the combined system, the outlets of the numerous main sewers being along the east bank of the Olentangy and Scioto Rivers. The dry-weather flow in the combined system, however, is intercepted and discharged into an intercepting sewer which starts at the north end of the city and runs south along the east bank of the two rivers, the outlet formerly being on the east bank of the Scioto River about 2¼ miles below the center of the city.

The West Side District is sewered largely on the separate system, the sewer outlets being along the west bank of the Scioto River. The

dry-weather flow in the combined sewers, however, is intercepted and discharged into the sanitary system.

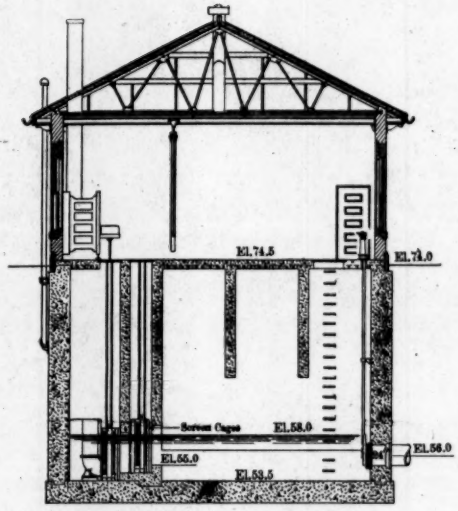
In the West Side District a portion of the ground is low, and, in the past, during periods of high water in the river, some of the sewers have overflowed, flooding certain of the streets and numerous cellars. As previously stated, the discharge of sewage into Alum Creek and the Scioto River during periods of low water had been the cause of offensive conditions.

*Outline of Sewage Problem.*—It should be mentioned here that no public water supply is taken from the Scioto River below Columbus. At Portsmouth, Ohio, 100 miles from Columbus, where the Scioto discharges into the Ohio River, however, the water supply is taken from the Ohio, but at a point some distance above the junction of the two rivers.

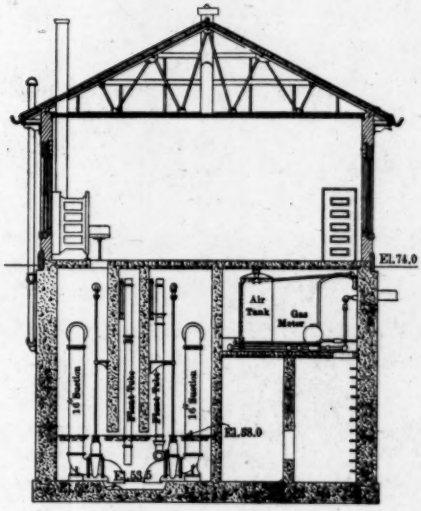
From the brief description of conditions just given, it will be seen that the sewage problem resolved itself first into the elimination of the direct discharge of sewage into Alum Creek and the Scioto River, which could be accomplished by the construction of purification works at one or more points, in which the treatment of the sewage would be such that the effluent, discharged into either Alum Creek or the Scioto River, would at all times be non-putrescible, and second, the prevention of the overflowing of the sewers on the west side.

*Preliminary Investigations.*—The first step taken toward the solution of the sewage problem was a joint investigation made by Julian Griggs, M. Am. Soc. C. E., Chief Engineer of the Department of Public Improvements, and John W. Alvord, M. Am. Soc. C. E., Consulting Engineer. Their report, which was made in May, 1898, was based on the best information then available, and the several projects which they studied involved all the well-known methods of purification which had received consideration, not only in the United States, but in England. Their recommendation, in brief, besides extensions and improvements to the sewerage system and the construction of pumping stations necessary to deliver the dry-weather sewage at the purification works, was the screening of the sewage and its double filtration through coke at a net rate of 500 000 gal. per acre per 24 hours. The works proposed were to treat 20 000 000 gal. of sewage per 24 hours, but it was advised that only 2 acres of the coke beds, practically contact filters, be built at the start, and that these beds be then operated for a year under

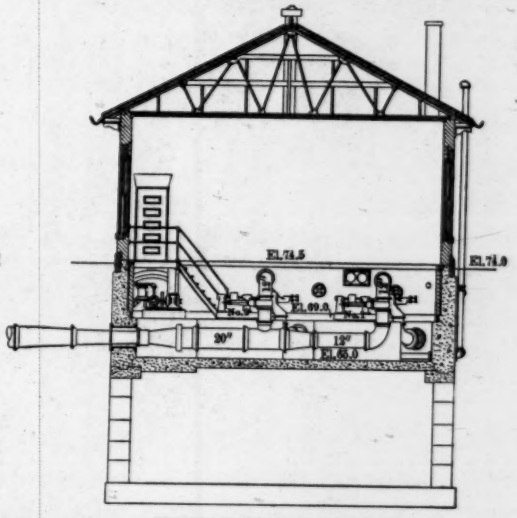
PLATE XXII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



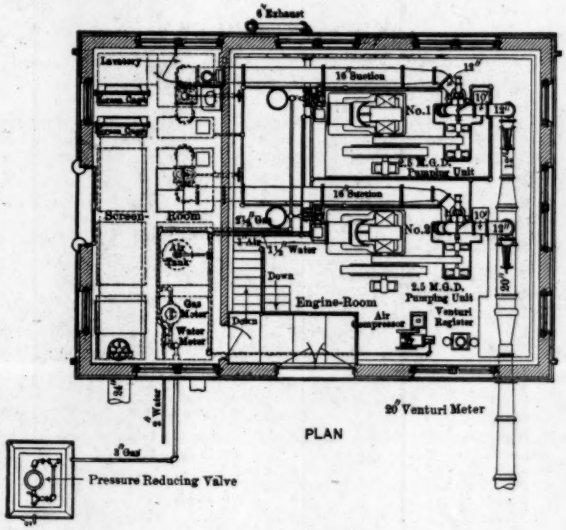

SECTION THROUGH SAND-CATCHER



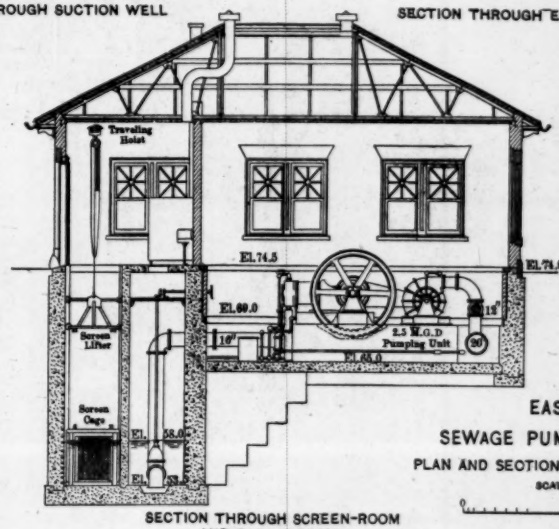

SECTION THROUGH SUCTION WELL




SECTION THROUGH ENGINE-ROOM




PLAN




SECTION THROUGH SCREEN-ROOM AND ENGINE-ROOM

EAST SIDE
SEWAGE PUMPING STATION
PLAN AND SECTIONS SHOWING MACHINERY
SCALE OF FEET
0 10 20

expert supervision, after which, from the practical experience gained, the remaining beds were to be constructed.

No further action was taken, after the submission of the report by Messrs. Alvord and Griggs, until 1901, when Mr. Rudolph Hering was asked to review the whole sewage problem. In May, 1901, Mr. Hering reported in favor of the construction of septic tanks followed by intermittent filtration through sand, endorsing also the previous recommendation that a portion only of the works be constructed at first and operated for a period of at least one year before designing and constructing the remainder. Mr. Hering also endorsed the recommendations made by Messrs. Alvord and Griggs relative to the construction of pumping stations and the revisions and extensions of the sewerage system. It was not until November, 1903, however, that the first funds were provided so that the carrying out of the sewage improvements was assured.

*Experimental Investigation.*—From the previous investigations and studies, the general character and scope of the various parts of the improvement had been reasonably well outlined, but the engineers were confronted with the problem of designing a purification works a part of which was to be built and operated experimentally for a year, and which must be arranged so as to fit in as an integral part of the permanent construction. After further thought and study, it was concluded that it would be a wiser plan to make an extended experimental investigation, on a practical scale, of the various methods of sewage purification, for a period of at least one year, in order to determine the most efficient and economical method, and then to design the purification works accordingly. The co-operation of the City Council was therefore asked, and it very generously responded by appropriating the sum of $46 000 for experimental purposes. Immediately following this appropriation, a sewage testing station was designed and built, in which, from August 16th, 1904, to July 30th, 1905, various methods of sewage purification were studied exhaustively. As it is not the purpose of this paper to discuss the results of this investigation, a full report of which has already been published,* it will be sufficient to state the indications of the experimental work, namely, that, under the local conditions, the Columbus sewage could be treated most satisfactorily and economically in a purification works comprising septic tanks,

* Report on Sewage Purification at Columbus, Ohio, 1905, by George A. Johnson, Assoc. M. Am. Soc. C. E.

sprinkling filters, and settling basins, and this method was therefore adopted. While the investigation showed that satisfactory results could be obtained by preliminary clarification and subsequent filtration through sand, it also showed, for the first time in the United States, that sprinkling filters could be operated in a northern climate and produce a satisfactory effluent at less cost than any other type of filter.

*Brief Outline of Works.*—The preliminary investigations made by Messrs. Griggs, Alvord, and Hering, and subsequent ones made by the engineering organization, indicated that it would be most advisable and economical to build and operate one purification works rather than two, and that the most feasible site for the works was on the Scioto River south of the city.

Briefly stated, the dry-weather flow of the whole city is brought to one point, where a pumping station, known as the Main Sewage Pumping Station, has been built. To accomplish this result, it has required the construction of a small pumping station near Alum Creek, known as the East Side Sewage Pumping Station, where the sewage from the East Side Sewer District is intercepted and pumped through a force main discharging into the upper end of one of the main sewers in the Intercepting Sewer District, the extension of the intercepting sewer across the Scioto River, and the construction of a new sanitary sewer connecting with the West Side Sewer District, and the reconstruction of a portion of the sewerage system in that district. From the Main Sewage Pumping Station the sewage is pumped through a force main to sewage purification works where the sewage is treated, the effluent from the works passing into the Scioto River. The Main Sewage Pumping Station is also arranged to pump storm-water from the West Side, one of the storm-water sewers having been extended to the pumping station. In addition, the work has included about 2.55 miles of levee construction, a railroad spur, 1.85 miles in length, and a single-track railroad bridge across the Scioto River. The location of the various parts of the work are shown on Fig. 1.

### East Side Sewage Pumping Station and Force Main.

The East Side Sewage Pumping Station is located on the south side of East Main Street and about 400 ft. west of Alum Creek. A general plan of the station and connections is shown on Fig. 13, and the detail of the pumping station on Plate XXII.

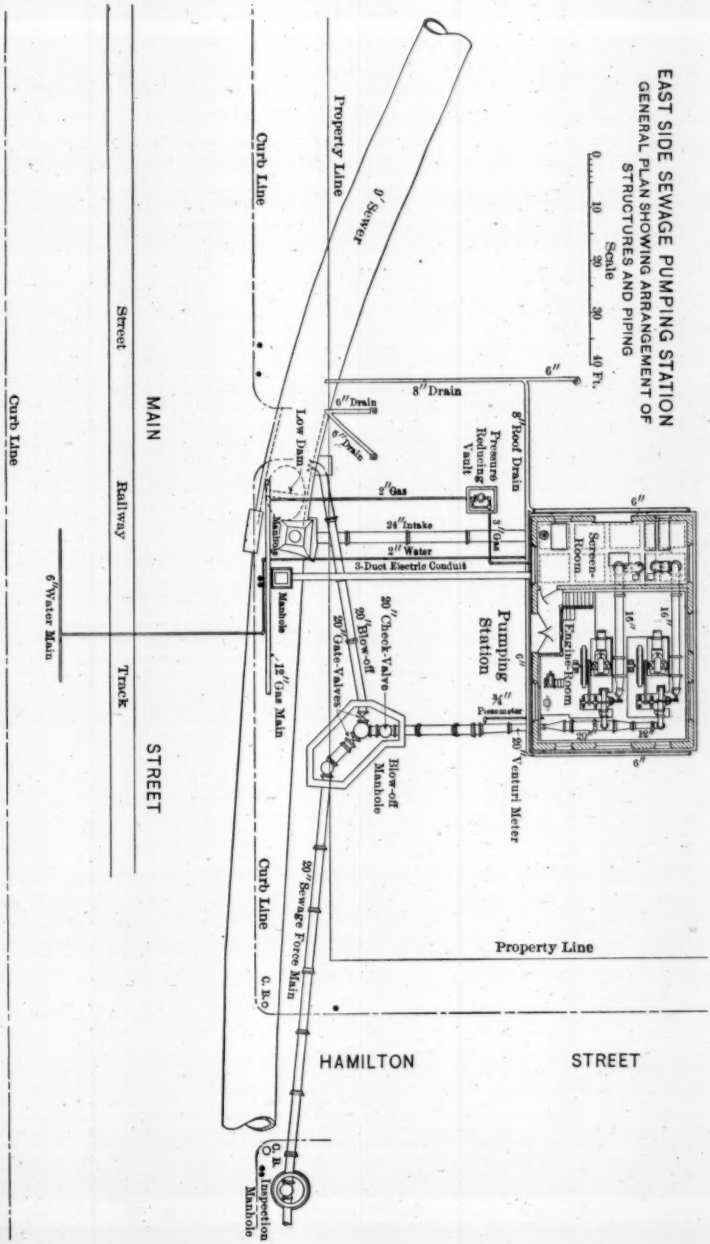

EAST SIDE SEWAGE PUMPING STATION
GENERAL PLAN SHOWING ARRANGEMENT OF STRUCTURES AND PIPING
Scale
0 10 20 30 40 Ft.
Property Line
9' Sewer
Curb Line
8" Drain
6" Drain
6" Drain
Low Dam
8" Roof Drain
Pressure Reducing Vault
2" Gas
24" Intake
2" Water
3" Gas
3-Duct Electric Conduit
Manhole
Manhole
Screen-Room
Engine-Room
Pumping Station
20" Check-Valve
20" Blow-off
20" Gate-Valves
12" Gas Main
¾" Piezometer
20" Venturi Meter
Blow-off Manhole
20" Sewage Force Main
C. R. O.
Property Line
HAMILTON STREET
C. R. O. Inspection Manhole
MAIN STREET
Street Railway Track
6" Water Main
Curb Line
Curb Line

FIG. 13.

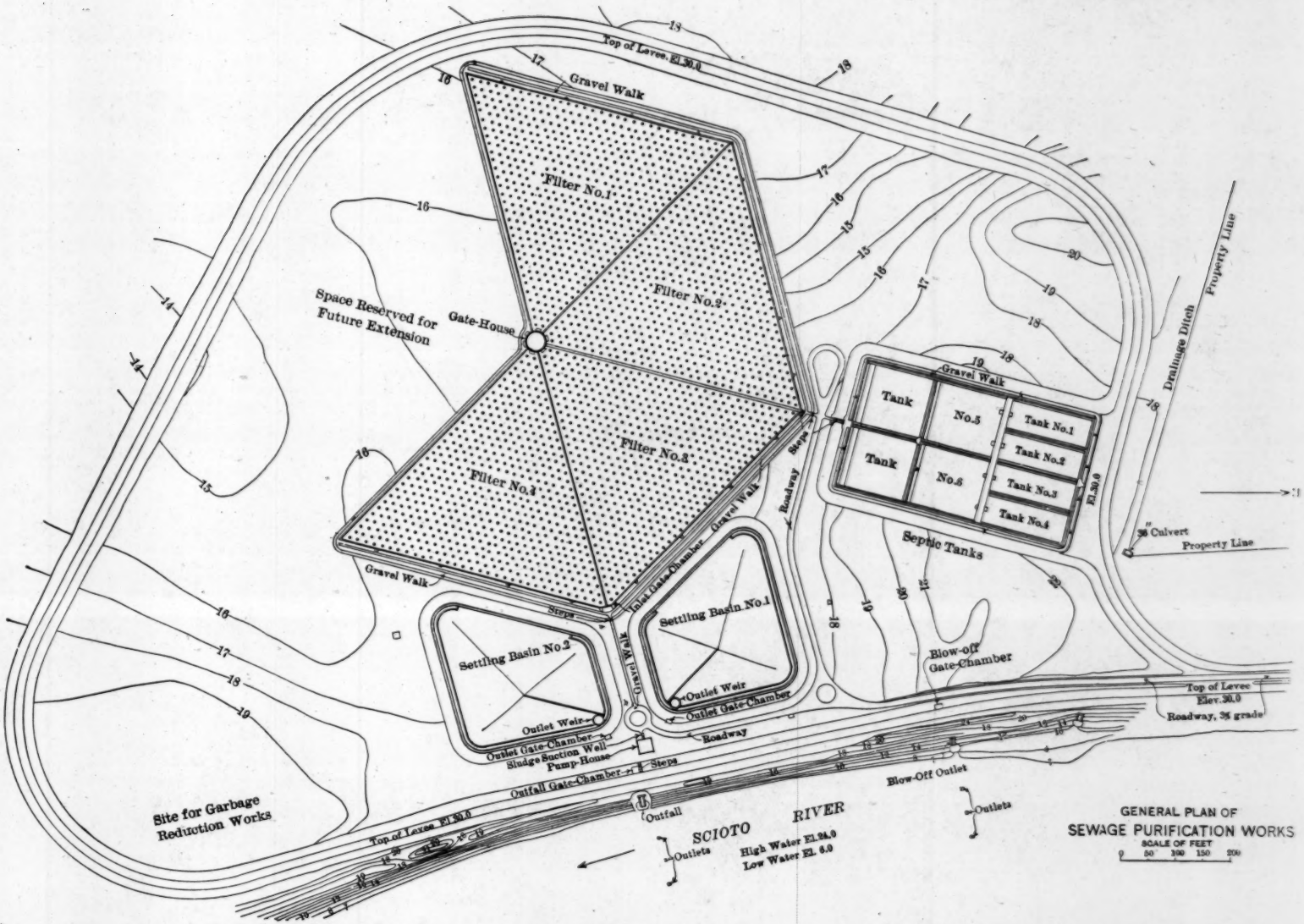
*Connections.*—Passing in front of the pumping station there is a 9-ft. combined sewer which serves as the outfall sewer for the East Side Sewer District. A low dam constructed in the bottom of this sewer intercepts the dry-weather flow and first wash of the storm flow, diverting it into a 24-in. intake pipe connecting with the substructure of the pumping station. Connections are also made with the water main and high-pressure natural-gas main in the street. The electric light and telephone wires are brought in through a three-duct vitrified conduit.

*Substructure.*—The sewage is first admitted to a long chamber, serving as a sand-catcher, is screened to remove the coarser matters in suspension, and then passes into the suction well. The screening device consists of two cages, of steel-frame construction, holding removable sets of screens made up of $\frac{3}{4}$-in. square bars, 1 in. apart in the clear. The cages are raised and lowered by hand by a movable screen lifter hung from a traveling hoist and runway just below the ceiling of the screen-room above. The substructure is of concrete, reinforced at various points. In the substructure of the engine-room, in which it was necessary to locate the pumps and engines on account of the suction lift, the walls are lined with hard vitrified red pressed brick.

*Superstructure.*—The walls of the superstructure are of brick, faced outside with red pressed brick. In the engine-room the walls are lined with light-buff speckled pressed brick, and in the screen-room with hard red brick. The stone trimmings are all of Bedford, Ind., limestone. The ceilings in both rooms are of plaster on metal lath fastened to the lower chords of the roof trusses. The roof is of 3-in. hollow terra cotta tile and slate carried by steel trusses and intermediate framing.

*Pumping Machinery.*—The pumping machinery is installed in duplicate. Each unit consists of a Columbus, horizontal, four-stroke-cycle, gas engine, connected by a Morse, silent-running, high-speed chain to a horizontal, single-stage, Worthington, volute pump with 12-in. suction and 10-in. discharge nozzles. The engine is capable of developing 90 h.p. when operating on natural gas having a thermal value of about 1 000 B. t. u. per cu. ft. When running together each unit has a rated capacity of 2 200 000 gal. per 24 hours against a head of 75 ft., and when running alone a maximum capacity of 2 900 000 gal. per 24 hours against a head of 63 ft. For starting the engines, the equipment includes a small motor-driven air compressor and air tank.

PLATE XXIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.




GENERAL PLAN OF
SEWAGE PURIFICATION WORKS
SCALE OF FEET
0 50 100 150 200

*Force Main.*—The sewage is pumped through a 20-in. cast-iron force main to a point about 8 180 ft. from the pumping station where it is discharged into the upper end of the Mound Street Sewer, this sewer in turn discharging into the intercepting sewer on the east bank of the Scioto River. The flow is measured by a 20-in. Venturi meter, the register, chart recorder, and manometer being placed in the pumping station. The meter tube is of special construction, and between the tube and the register and manometer, oil seals are interposed to keep the sewage out from the latter.

### Levees, Railroad Spur, and Bridge.

The sites chosen for the main sewage pumping station and for the purification works, while possessing many advantages, were not readily accessible for the delivery of materials, not being near a railroad, and the Scioto River not being a navigable stream. In considering the cost of the work, it was seen that a large expense would be incurred in hauling construction materials, for which there would be no apparent return. It was decided, therefore, that it would be economical in the long run to build a permanent railroad spur connecting with the main line of the Hocking Valley Railway, over which cars could be switched directly to the sites of the two works.

The ground near the river south of the city is relatively low, and during high floods was sometimes submerged, the river overflowing the old existing levees. In order that the railroad spur might at all times be above high water, new levees have been constructed, on which the spur has been built. The levees, therefore, serve the double purpose of providing an excellent location for the spur and of protecting a large amount of property. The city was especially interested in building the levees, as it is the owner of a large tract of the land which was sometimes submerged.

*Levees and Railroad Spur.*—The spur starts at the Hocking Valley Railway, at the foot of Moler Street, and extends southwest to a point where it crosses the river by a bridge, after which it follows south along the west bank of the river past the pumping station and down to the purification works. The total length of the spur is 1.85 miles. The levees have a top width of 16 ft. and side slopes of 1.5 horizontal to 1 vertical, are about 13 ft. above the general level of the ground, and were built of a mixture of loamy and sandy material obtained along the line. At several points the levees are pierced by small con-

crete culverts, the outlets at the river bank being protected by flap-valves.

*Bridge.*—The spur is carried across the river by a single-track through bridge, consisting of three spans, 150 ft. 6 in. in length, or a total of 457 ft. 6 in. from center to center of end pins. The substructure consists of two abutments and two piers of concrete supported on timber piles. The abutments have a total height of 32 ft. 8 in. and the piers a height of 34 ft. The superstructure consists of steel, pin-connected, Pratt trusses, designed for a live load corresponding to Cooper's Class *E*-40 loading. The bridge has a clear width of 14 ft. between trusses and a clear height of 22 ft. above the base of the rails. The timber floor is carried on four track stringers.

### Sewer, Water, and Gas Main Extensions.

*Intercepting Sewer.*—The intercepting sewer, which drains the greater part of the built-up portion of the city, formerly discharged on the east bank of the river. This sewer has been extended across under the river a distance of about 540 ft. to a sand-catcher connected with the Main Sewage Pumping Station. The extension consists of a 48-in. cast-iron pipe surrounded by concrete. On the east bank, just back of the connection with the old sewer, a relief outlet has been provided which will open automatically if the flow of sewage is shut off at the sand-catcher or at the pumping station.

*West Side Sanitary Sewer.*—In order to bring the dry-weather flow of sewage from the west part of the city to the pumping station, a new sewer, 1.85 miles in length, called the West Side Sanitary Sewer, has been built. For a portion of the way the sewer is of brick and concrete, but, from the point where it is built in connection with the Renick Run Storm-Water Sewer, it is entirely of concrete. At the upper end its diameter is 3 ft., enlarging farther down to 3 ft. 6 in., and the concrete section, in connection with the storm-water sewer, is 3 ft. 6 in. by 3 ft. 6 in., with vertical side-walls. An outlet to the river has been provided, and, where this sewer joins with the storm-water sewer, a sand-catcher and relief outlet have been built. In order to divert the flow of sewage to this new sewer, certain reconstruction of the sewerage system in the west part of the city has been necessary.

*Renick Run Storm-Water Sewer.*—The storm-water from a part of the west side of the city is carried away by the Renick Run Storm-

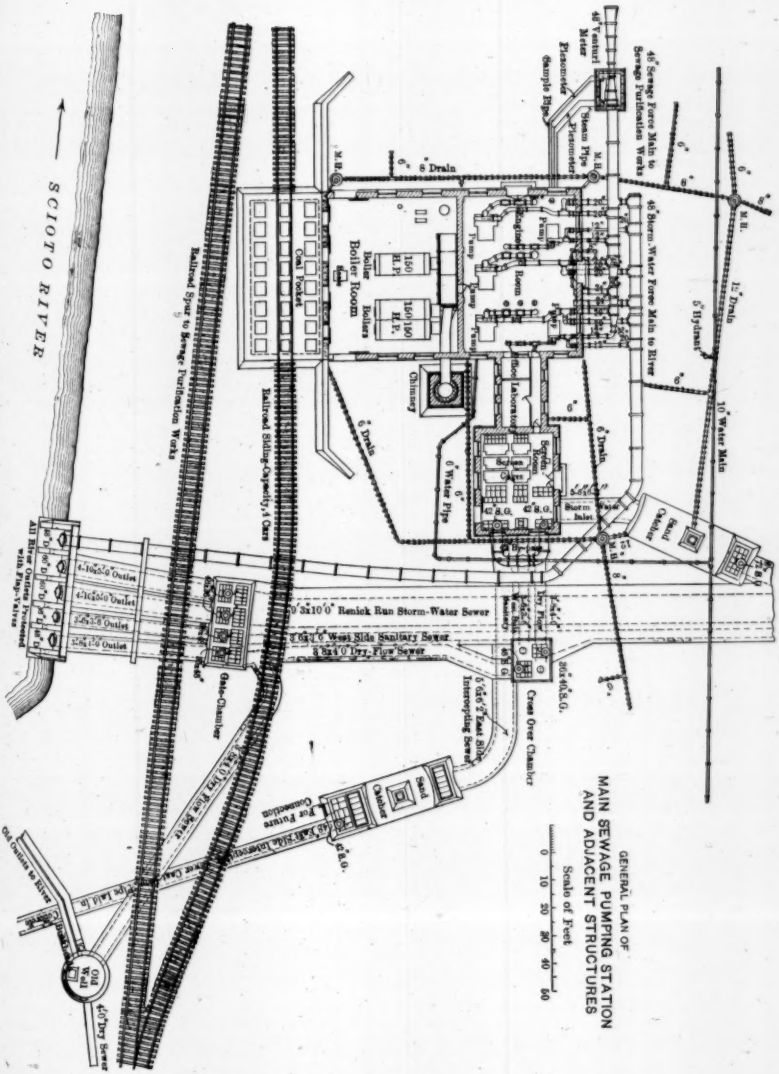

GENERAL PLAN OF
MAIN SEWAGE PUMPING STATION
AND ADJACENT STRUCTURES
Scale of Feet
0 10 20 30 40 50
SCIOTO RIVER
48" Sewage Force Main to Sewage Purification Works
48" Storm-Water Force Main to River
48" Venturi Meter
Piezometer
Sample Pipe
Steam Pipe
Piezometer
8" Drain
Boiler Room
Boilers
Coal Pocket
Chimney
Office Laboratory
Screen Room
Screen Cages
Storm Inlet
Sand Catcher
12" Drain
5" Hydrant
10" Water Main
6" Drain
6" Water Pipe
Railroad Spur to Sewage Purification Works
Railroad Siding-Capacity, 4 Cars
9'3"x10'0" Renick Run Storm-Water Sewer
3'6"x3'6" West Side Sanitary Sewer
3'8"x4'0" Dry-Flow Sewer
Gate-Chamber
Cross Over Chamber
Sand Catcher
For Future Connection
Old Outlets to River
Old Wall
4'-0" Dry Sewer
All River Outlets Protected with Flap-Valves

FIG. 14.

Water Sewer which discharged formerly into the Renick Run Ditch, on the property of the city, about 3 050 ft. west of the pumping station. This sewer has been extended to the pumping station and river. The sewer is of concrete, with vertical side-walls, is 8 ft. by 7 ft. 4 in. enlarging to 10 ft. by 9 ft. 3 in., and is built in connection with the West Side Sanitary Sewer. There is a sand-catcher on the branch leading to the pumping station. At the Renick Run Ditch, there is also a relief which will come into play if, for any reason, the pumping station should cease pumping storm-water during a period of high water in the river.

*Dry-Flow Sewer.*—A portion of the sanitary sewage from the West Side is also carried by the old 4-ft. Dry-Flow Sewer. This sewer, although at present in bad shape, has been extended to the pumping station and a new outlet to the river provided. With additional extensions of the sewerage system in the city, it is proposed to abandon it as a sanitary sewer and use it only for storm-water.

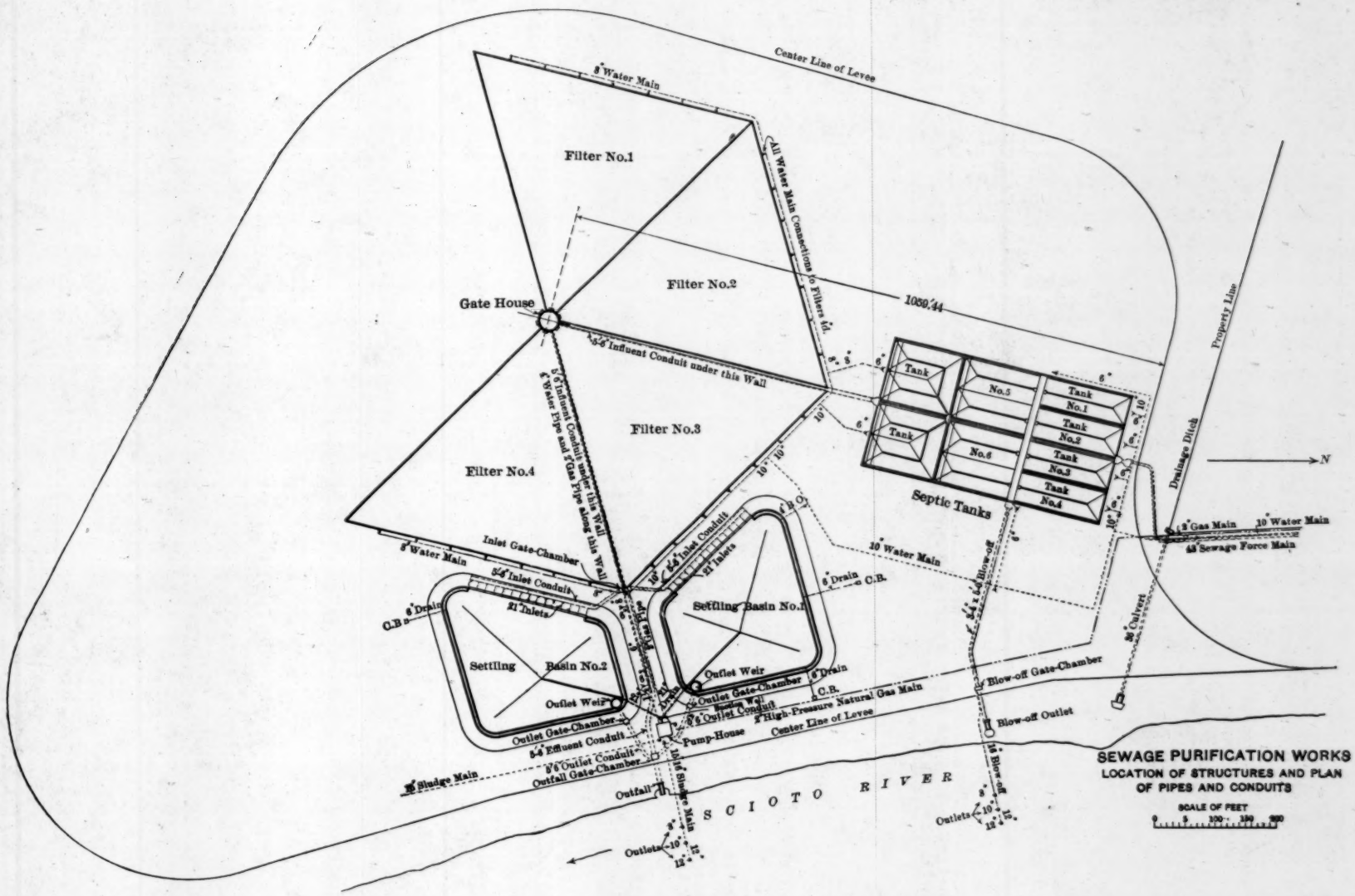
*Water Main.*—To provide a suitable water supply under pressure at the pumping station and purification works, it has been necessary to lay a 10-in. water main, 2.05 miles in length, connecting with the distribution system in the city at the corner of High Street and Neff Avenue.

*Gas Main.*—For supplying natural gas for light and power at the sewage purification works, a 2-in. high-pressure gas main, 1.65 miles in length, has been laid from the high-pressure gas main of the Federal Gas Company in Stimmel Road to the purification works.

## Main Sewage Pumping Station.

The Main Sewage Pumping Station is on the west bank of the Scioto River about 2¼ miles south of the center of the city. Fig. 14 shows the location of the pumping station and connections, and the structures immediately adjacent. Although the station is protected from the river by the new levee, it was considered wise, as an additional safeguard, to enclose the pumping station lot with a levee also. The levee around the lot has the same dimensions as the levees on which the railroad spur is built, but this levee and that back of the station immediately adjacent to the river were built with carefully selected materials placed in layers and well rolled. The general arrangement of the machinery and equipment, and sections through the building, are shown on Fig. 15.

PLATE XXIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.




SEWAGE PURIFICATION WORKS
LOCATION OF STRUCTURES AND PLAN
OF PIPES AND CONDUITS
SCALE OF FEET
0 5 100 200 300

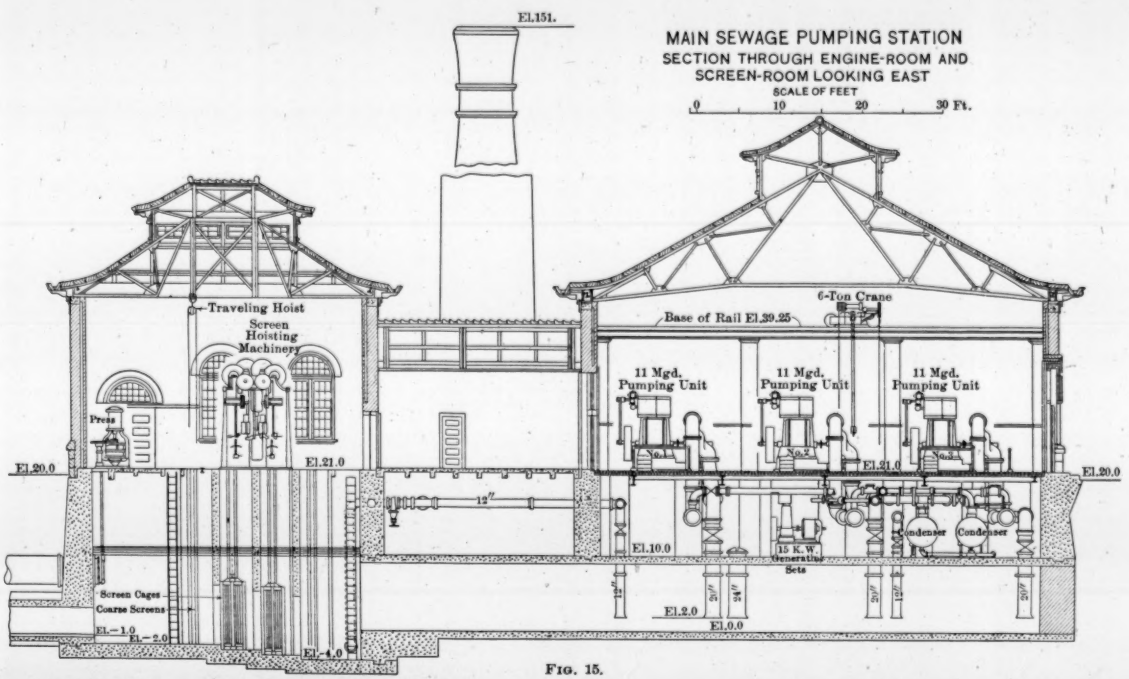

MAIN SEWAGE PUMPING STATION
SECTION THROUGH ENGINE-ROOM AND
SCREEN-ROOM LOOKING EAST
SCALE OF FEET
0 10 20 30 Ft.
El.151.
Traveling Hoist
Screen
Hoisting
Machinery
Press
El.20.0
El.21.0
Screen Cages
Coarse Screens
El.−1.0
El.−2.0
El.−4.0
12"
6-Ton Crane
Base of Rail El.39.25
11 Mgd.
Pumping Unit
11 Mgd.
Pumping Unit
11 Mgd.
Pumping Unit
El.21.0
El.20.0
El.10.0
15 K.W.
Generator
Sets
Condenser
Condenser
12"
20"
24"
20"
12"
20"
El.2.0
El.0.0

FIG. 15.

*Connections.*—The connections to the pumping station are shown on Fig. 14, and need but little description. The sanitary sewage, and the storm-water when it is necessary to pump it, first flows into the substructure under the screen-room, where it is screened, then passes into the suction wells and is pumped out through either or both of the force mains. One force main, for the sanitary sewage, leads to the purification works, about 1.2 miles away, and the other, for the storm-water, leads to the river directly back of the pumping station.

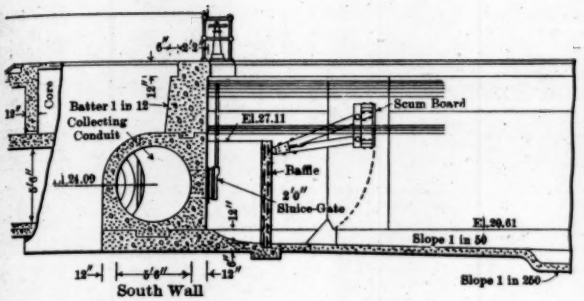
*Building.*—The substructure consists principally of screen chambers and of a basement under the engine-room. Below the basement there are three suction wells, one for the East Side sanitary sewage, one for the West Side sanitary sewage, and the third for the West Side storm-water. By means of a by-pass outside of the screen chambers, any one or all of the wells can be used. The substructure is entirely of concrete, reinforced at points.

The superstructure consists of a screen-room, engine-room, boiler-room, office, lavatory, and coal pocket. The building proper is of brick and the coal pocket of concrete, the type of construction in both cases being in general similar to that of the Scioto River Pumping Station, already described. The coal pocket has a capacity of 380 tons, or about 40 days' supply at the present rate of consumption.

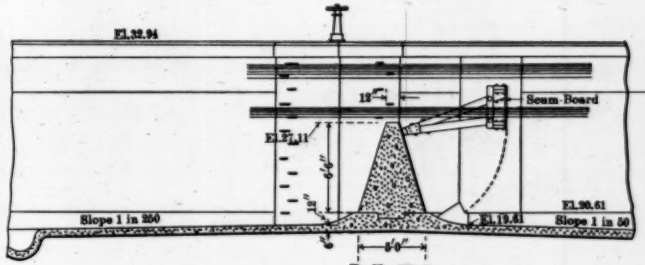
The chimney, which is of hollow radial brick construction, built by the Alphons Custodis Chimney Construction Company, is 5 ft. in diameter inside the fire-brick lining, and 130 ft. high above the boiler-room floor. The foundation of the chimney is carried on timber piles.

High water in the river is about 6 ft. above the engine-room floor, and in case of a break which would flood the pumping-station lot the station itself would be flooded. To care for this emergency, stop-plank grooves have been built in all the window and door openings, and a full set of stop-planks provided.

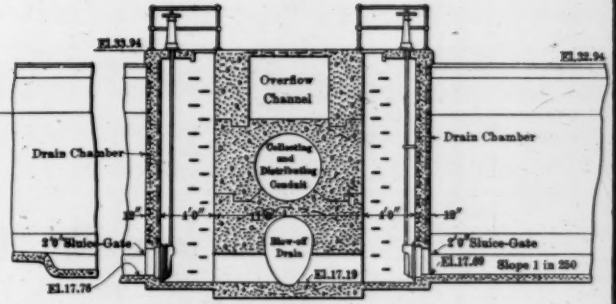
*Screening Devices.*—In the screen chambers for the East Side and West Side sanitary sewage, the screening devices consist of cages of steel-frame construction holding removable sets of screens, two cages to each chamber. In the front cages the screens are of $\frac{3}{4}$-in. round bars 1 in. apart, in the clear, and in the rear cages of $\frac{3}{8}$-in. round bars $\frac{1}{2}$ in. apart in the clear. On the floor above the chambers there is an iron superstructure from which the cages are hung, the cages being raised and lowered by simple reversing steam engines carried on the superstructure. In the screen chamber for the West Side storm-water,




South Wall

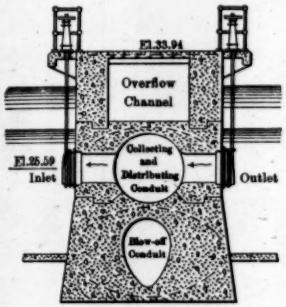



Baffle Wall

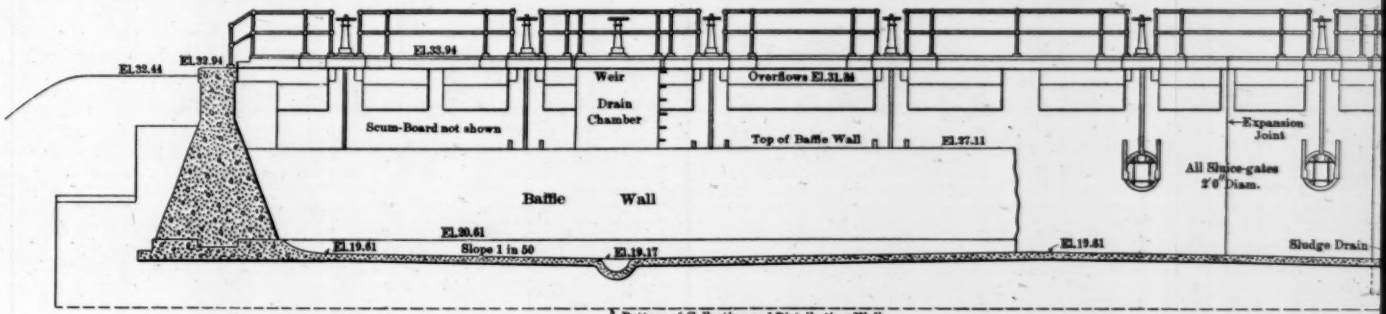



Collecting and Distributing Wall

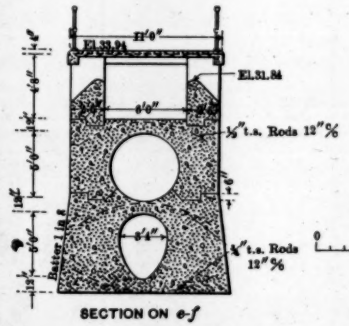
LONGITUDINAL SECTION THROUGH TANKS NOS. 6 AND 4




SECTION ON *g-h*




ELEVATION OF WEST HALF OF COLLECTING AND DISTRIBUTING WALL LOOKING NORTH

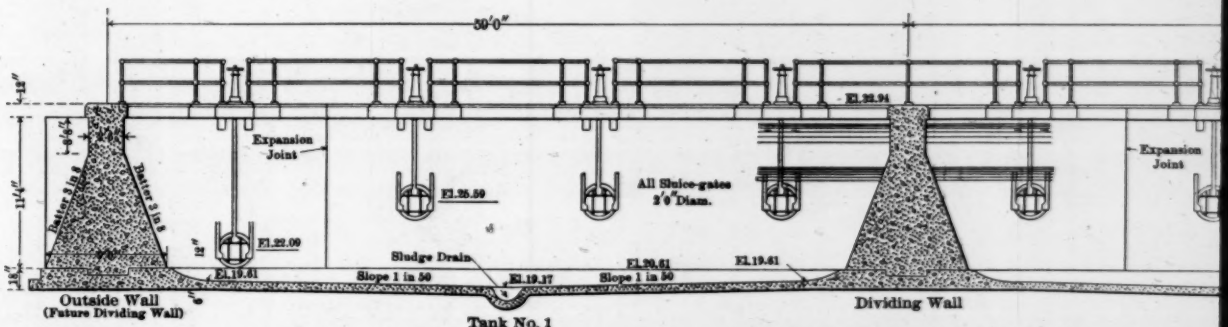



SECTION ON *e-f*

SEPTIC TANKS

SCALE OF FEET

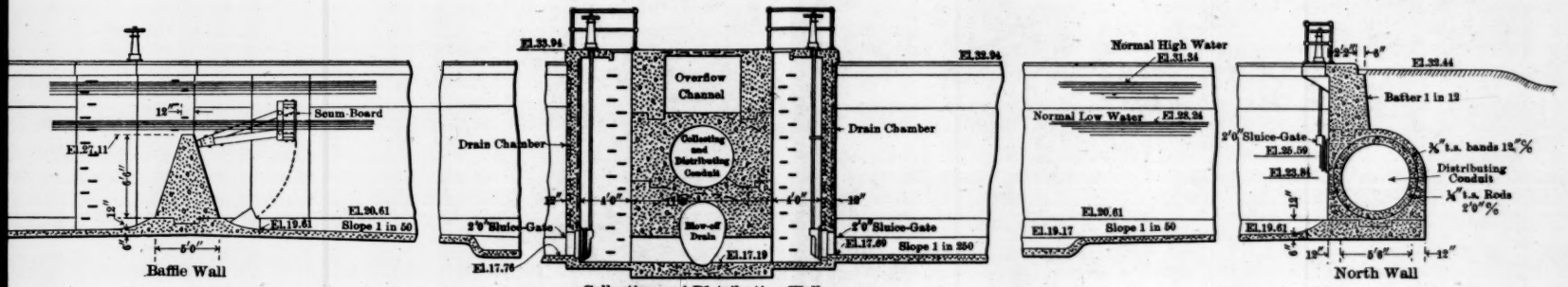
0 4 8 12 16 20



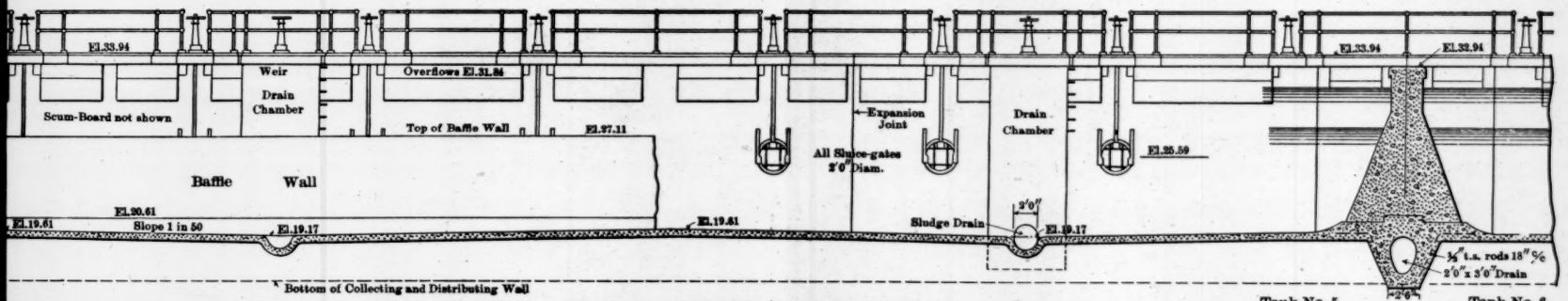

Tank No. 1

ELEVATION OF WEST HALF OF NORTH WALL

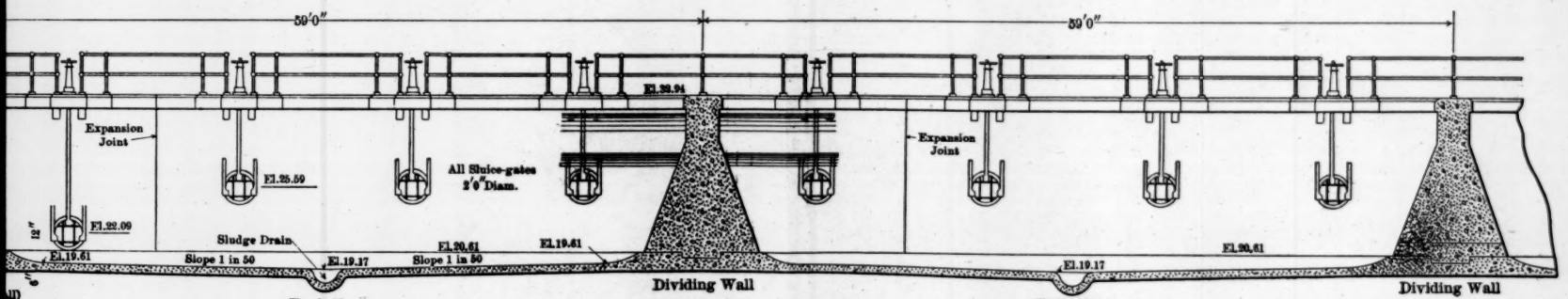
PLATE XXV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.




LONGITUDINAL SECTION THROUGH TANKS NOS. 6 AND 4




ELEVATION OF WEST HALF OF COLLECTING AND DISTRIBUTING WALL LOOKING NORTH




ELEVATION OF WEST HALF OF NORTH WALL

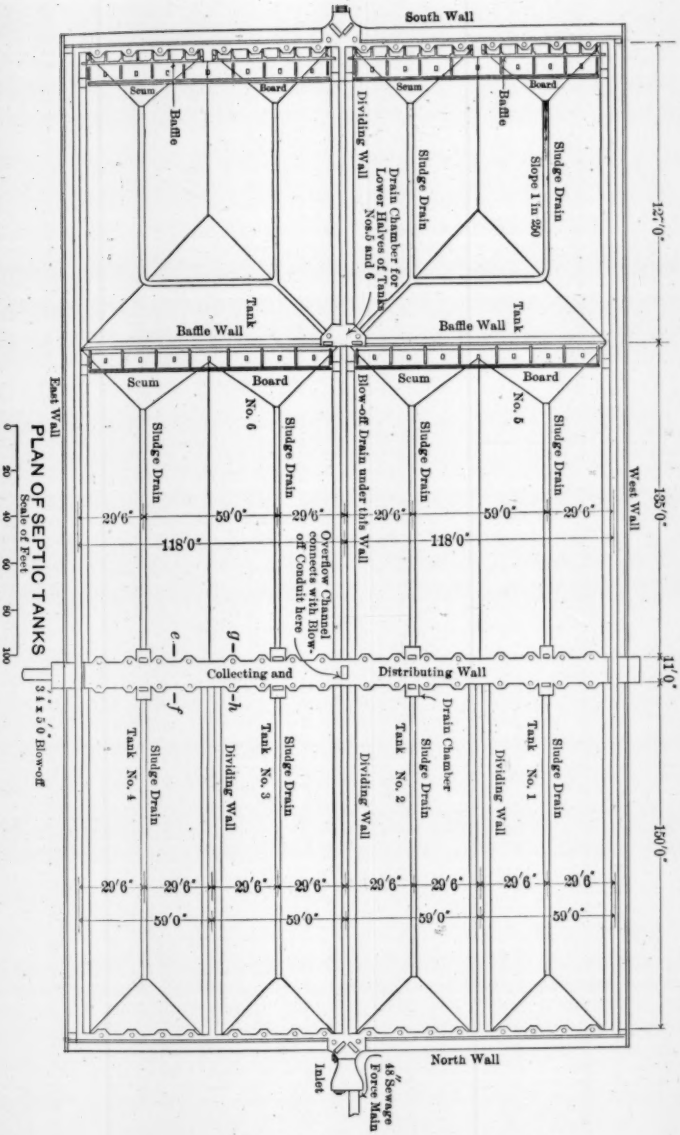

South Wall
Scum
Board
Baffle
Dividing Wall
Drain Chamber for Lower Halves of Tanks Nos. 5 and 6
Sludge Drain
Slope 1 in 200
Tank
Baffle Wall
No. 6
No. 5
Blow-off Drain under this Wall
Overflow Channel connects with Blow-off Conduit here
Collecting and
Distributing Wall
Drain Chamber
Tank No. 4
Tank No. 3
Tank No. 2
Tank No. 1
East Wall
West Wall
North Wall
Inlet
48" Sewage Force Main
3 ft x 5' 0" Blow-off
127'0"
135'0"
11'0"
150'0"
29'6"
59'0"
118'0"
PLAN OF SEPTIC TANKS
Scale of Feet
0 20 40 60 80 100

FIG. 16.

which is used only when it is necessary to pump storm-water, there is a double set of vertical steel-frame screens of ¾-in. round bars 1 in. apart, in the clear, each section being provided with a catch-pan. The screens are raised and lowered by hand by a movable screen lifter hung from a traveling hoist and runway carried on the lower chord of one of the roof trusses. The material removed from the screens is disposed of on land.

*Low-Lift Pumping Machinery.*—For pumping the sewage and storm-water, five low-lift pumping units have been installed, space being left for a sixth unit. Each unit consists of a single-suction, horizontal, Worthington, volute pump, direct-connected to a vertical, cross-compound, Reeves engine. Three of the pumps have 20-in. suction and discharge pipes, and have a normal capacity of 11 000 000 gal. per 24 hours against a total suction and discharge head of 25 ft., and a maximum rated capacity of 14 000 000 gal. per 24 hours against a total head of 30 ft. The two smaller pumps have 12-in. suction and discharge pipes, and have a normal capacity of 4 000 000 gal. per 24 hours against a total suction and discharge head of 28 ft., and a maximum rated capacity of 5 000 000 gal. per 24 hours against a total head of 32 ft. Each of the five units can draw from any one of the three suction wells, as desired.

*Boilers and Accessories.*—In the boiler-room there are three 150-h.p., Babcock and Wilcox, horizontal, water-tube boilers carrying steam at 160 lb. pressure, space being left for a fourth boiler. In the basement of the engine-room there are two surface condensers and two vacuum pumps, and in the boiler-room a Green economizer, two boiler feed pumps, a heater, and a hot well.

*Generators and Crane.*—The building is lighted by two 10-kw., 250-volt, direct-current generators, each direct-connected to a vertical, simple engine. In the engine-room there is a 6-ton, Case, hand, traveling crane having a span of 41 ft. 4 in. and a travel the full length of the room.

### Connections Between Main Sewage Pumping Station and Sewage Purification Works.

From the pumping station the sewage is pumped through a 48-in. cast-iron force main, 1.2 miles in length, to the sewage purification works. In the force main, just outside of the pumping station, is placed a 48-in. Venturi meter of special construction, similar to that

PLATE XXVI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

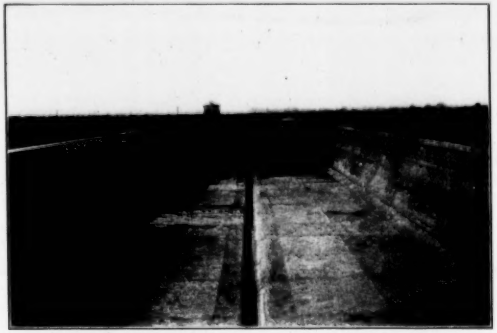


FIG. 1.—VIEW OF PRIMARY SEPTIC TANK, LOOKING SOUTH.

FIG. 2.—PRIMARY SEPTIC TANK, SHOWING SLUDGE JUST BEFORE CLEANING.

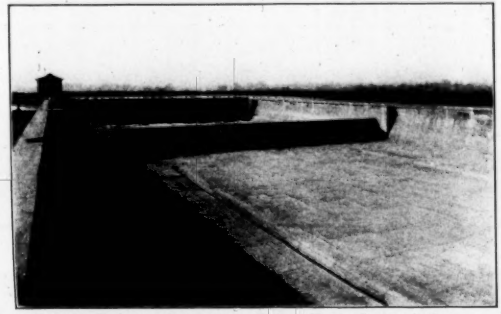


FIG. 3.—VIEW OF SECONDARY SEPTIC TANK, LOOKING SOUTH.

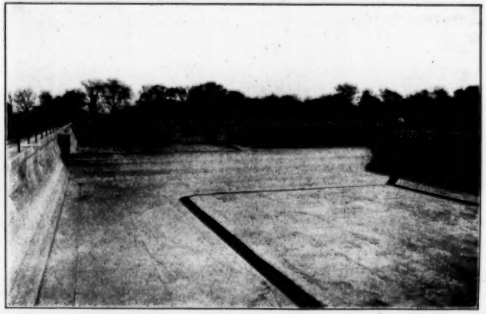


FIG. 4.—VIEW OF SECONDARY SEPTIC TANK, LOOKING NORTH.

used on the East Side sewage force main. The primary indicating and registering devices are in the engine-room.

A pole line from the pumping station to the purification works carries telephone wires and wires connecting with a secondary Venturi indicating and recording device in the gate-house at the purification works.

## The Sewage Purification Works.

The sewage purification works are on the west bank of the Scioto River, the upper end being about 1.2 miles below the Main Sewage Pumping Station and about 3.5 miles south of the center of the city.

*Type and Capacity.*—As previously mentioned, the purification works comprise septic tanks, sprinkling filters, and settling basins, the present installation having a net normal capacity of 20 000 000 gal. per 24 hours. The arrangement of the works, however, is such that they may be extended to an ultimate capacity of 30 000 000 gal. per 24 hours, and the main conduits will carry 45 000 000 gal. per 24 hours. A general plan of the works is given on Plate XXIII, and on Plate XXIV is shown more in detail the arrangement of the several structures and the layout of the various conduits and pipe lines.

It will probably be noticed by some that certain of the details, especially in the sprinkling filters, are somewhat different from what might be said to be current practice. In considering these details, however, it should be borne in mind that the Columbus sewage purification works were the first designed, and at present are the largest of their type now under operation, in the United States. When the works were designed, in 1905, the only precedent was English practice, where the sewage treated was much stronger than is that at Columbus, and, while excellent results had been obtained from the English works, many of the details adopted there would hardly have been, and still would not be, suitable for works subject to periods of severe winter weather, as in Columbus.

During the last four years much thought and study have been given to improving the details of construction and operation of sprinkling filters in the United States, and while, as previously mentioned, somewhat different details have been adopted in some of the more recent works, an examination of the designs seems to indicate that the details adopted and the experience obtained at Columbus have served as a basis from which to work.

*Levee.*—For protection from floods, the works are surrounded by a levee about 6 100 ft. long, its top being 6 ft. above the highest recorded water level in the river and from 10 to 15 ft. above the ground. The levee is 16 ft. wide on top, and has side slopes of 1½ horizontal to 1 vertical, the inner slope being dressed with loam and seeded. The railroad spur, which terminated on the levee east of Settling Basin No. 1, has been extended, since the purification works were finished, to connect with the garbage reduction works now under construction. A branch spur runs over to the north end of the septic tanks.

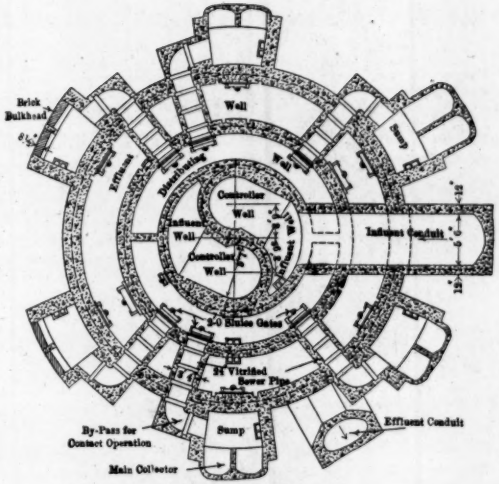
## Septic Tanks.

There are six septic tanks, four so-called primary tanks and two secondary tanks; the details are shown on Plate XXV. The primary tanks are 56 ft. 6 in. by 150 ft., and the secondary tanks are 115 ft. 6 in. by 262 ft. The tanks, throughout, are of concrete, are not covered, and are approximately 12 ft. deep to the high-water line. Each primary tank has a capacity of 710 000 gal. and each secondary tank 2 590 000 gal. The four primary tanks have a total capacity of 2 840 000 gal. and the two secondary tanks a total of 5 180 000 gal., making a grand total of 8 020 000 gal.

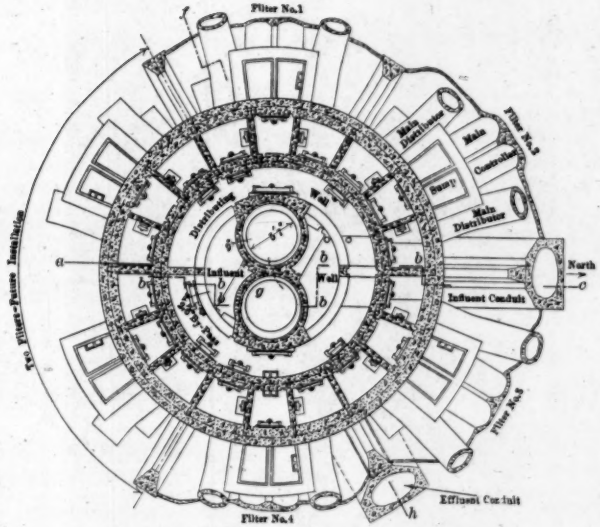
*Design.*—The tanks were designed with the object of not only placing the outlets as far as possible from the inlets, but also of keeping the sludge as much as possible away from the outlets, this being accomplished by dividing the tanks longitudinally by transverse walls into three sections. To meet varying conditions in the character of the sewage and in the quantity treated, the design was made very flexible, it being possible to use any combination of one or more primary tanks with either or both secondary tanks.

*Operation.*—As designed, the tanks were to be operated so that the rate of discharge from them would be practically constant during the 24 hours, the rate to be adjusted so that the total quantity drawn out would be as nearly as possible equal to the total quantity pumped in. As the rate of pumping varies from hour to hour, the surface level in the tanks, of course, fluctuates. With the mean hourly variation in the dry-weather flow, as determined during the experiments at the testing station, with the tanks all in service, and with a total flow of 20 000 000 gal. in 24 hours, the fluctuation would amount to about 3.1 ft., giving a minimum depth of about 8.9 ft. and a maximum depth of about 12 ft. in the tanks. On this basis, the average period of flow

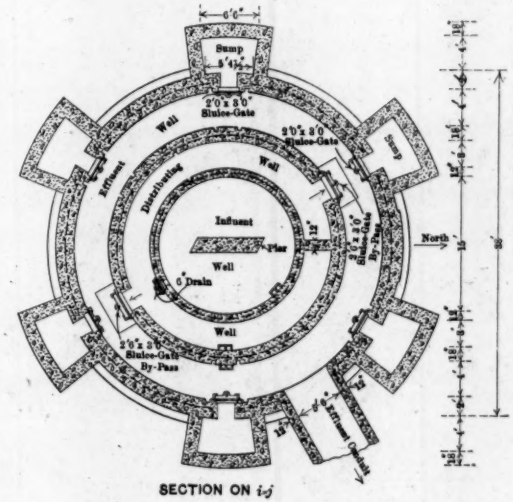
PLATE XXVII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



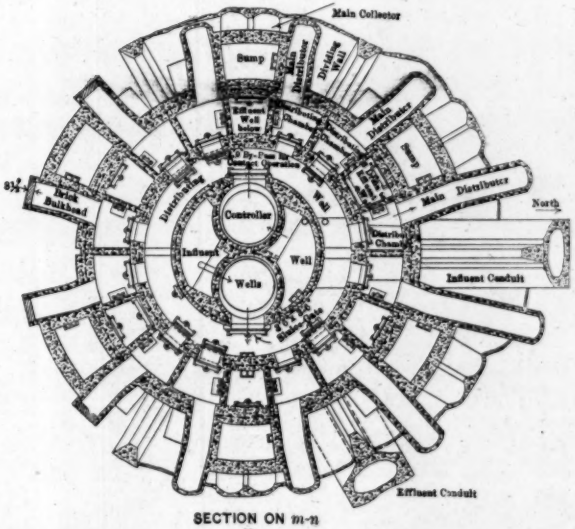

SECTION ON *k-l*




SECTION ON *o-p*

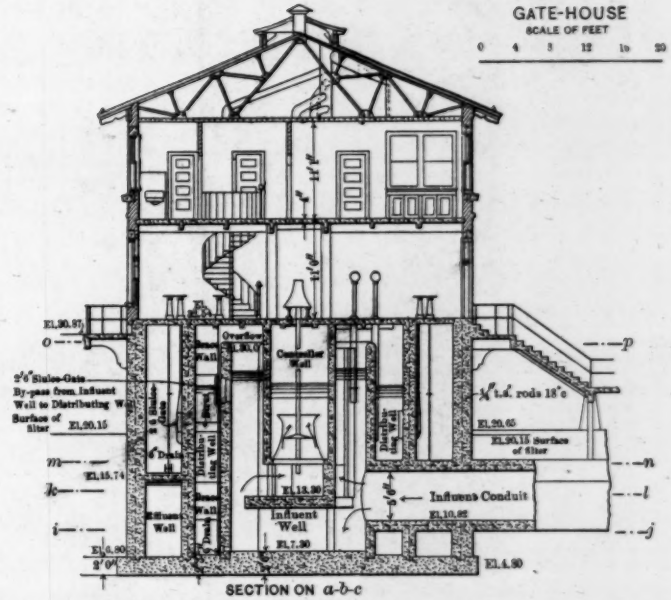



SECTION ON *i-j*

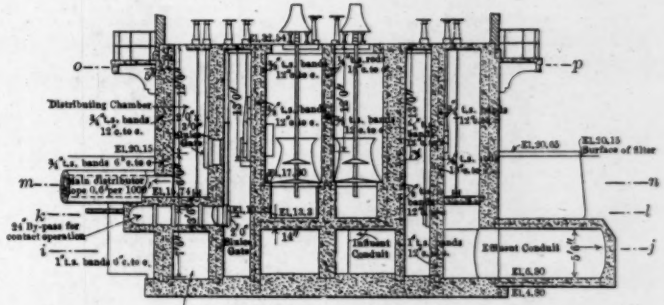



SECTION ON *m-n*

GATE-HOUSE
SCALE OF FEET
0 4 8 12 16 20




SECTION ON *a-b-c*




SECTION ON *f-g-h*

through the tanks would be about 8½ hours. In the operation of the works, however, it has been found that satisfactory results have been obtained by maintaining a constant level in the tanks, and the tanks are now operated in this way.

*North Wall.*—The 48-in. sewage force main terminates in a bell-mouth at the center of the north wall. The north wall is of a combined construction, consisting of a 5 ft. 6-in. reinforced distributing conduit carrying a small retaining wall above. Sewage is admitted into each primary tank from the top of the conduit portion through four 2-ft. sluice-gates, the center of the gates being about 2 ft. 8 in. below the low-water line in the tanks. By means of grooves and movable stop-planks, the distributing conduit may be divided into two sections, so that either half may be drained for inspection while the other half is in service.

*Collecting and Distributing Wall.*—The primary tanks are separated from the secondary tanks by a heavy wall of cored construction, called the collecting and distributing wall. In the middle of this wall there is a 5-ft. collecting and distributing conduit, sewage from each primary tank flowing into the conduit through four 2-ft. sluice-gates, and passing out into each secondary tank through eight 2-ft. sluice-gates. In the bottom of the wall there is a 3 ft. 4-in. by 5-ft. blow-off conduit, and in the top there is an overflow channel which connects with the blow-off conduit below, sewage from the primary and secondary tanks flowing into the overflow channel over numerous weirs ranged along each side of the channel. These weirs would come into play only to prevent overflowing the outside walls of the tanks.

The sludge drains, in the primary tanks and in the upper section of each secondary tank, discharge, through small drain chambers, directly into the blow-off conduit in the collecting and distributing wall. In the lower section of each secondary tank the sludge drains discharge into a drain chamber located in the line of the dividing wall between the secondary tanks, and thence through a 2 by 3-ft. blow-off drain under the dividing wall into the blow-off conduit in the collecting and distributing wall. The arrangement of the sludge drains permits each primary tank and each section of each secondary tank to be drained independently.

*Baffle Wall.*—Each secondary tank is divided into two sections by a low baffle wall, to hold back the sludge at the bottom of the upper half of the tank, the top of the wall being about 1 ft. below low-water

level. On the up-stream side of the wall, and hinged to it, there is a floating scum-board, of cypress, to hold back any scum which might form in the upper half of the tank.

*South Wall.*—The south wall is similar in construction to the north wall, but the collecting conduit is not reinforced. The effluent from each secondary tank is drawn off through eight 2-ft. sluice-gates, a reinforced concrete baffle and a floating scum-board holding back the sludge and any scum which might possibly form.

*Dividing Walls and Floors.*—All the dividing walls have a gravity section. The east and west outside walls have the same section as the dividing walls, as they will become dividing walls when the tanks are extended. The floors are all 6 in. in thickness, and no special attempt was made to make them water-tight, as it was thought that the joints between the floor-blocks would rapidly silt up and become tight.

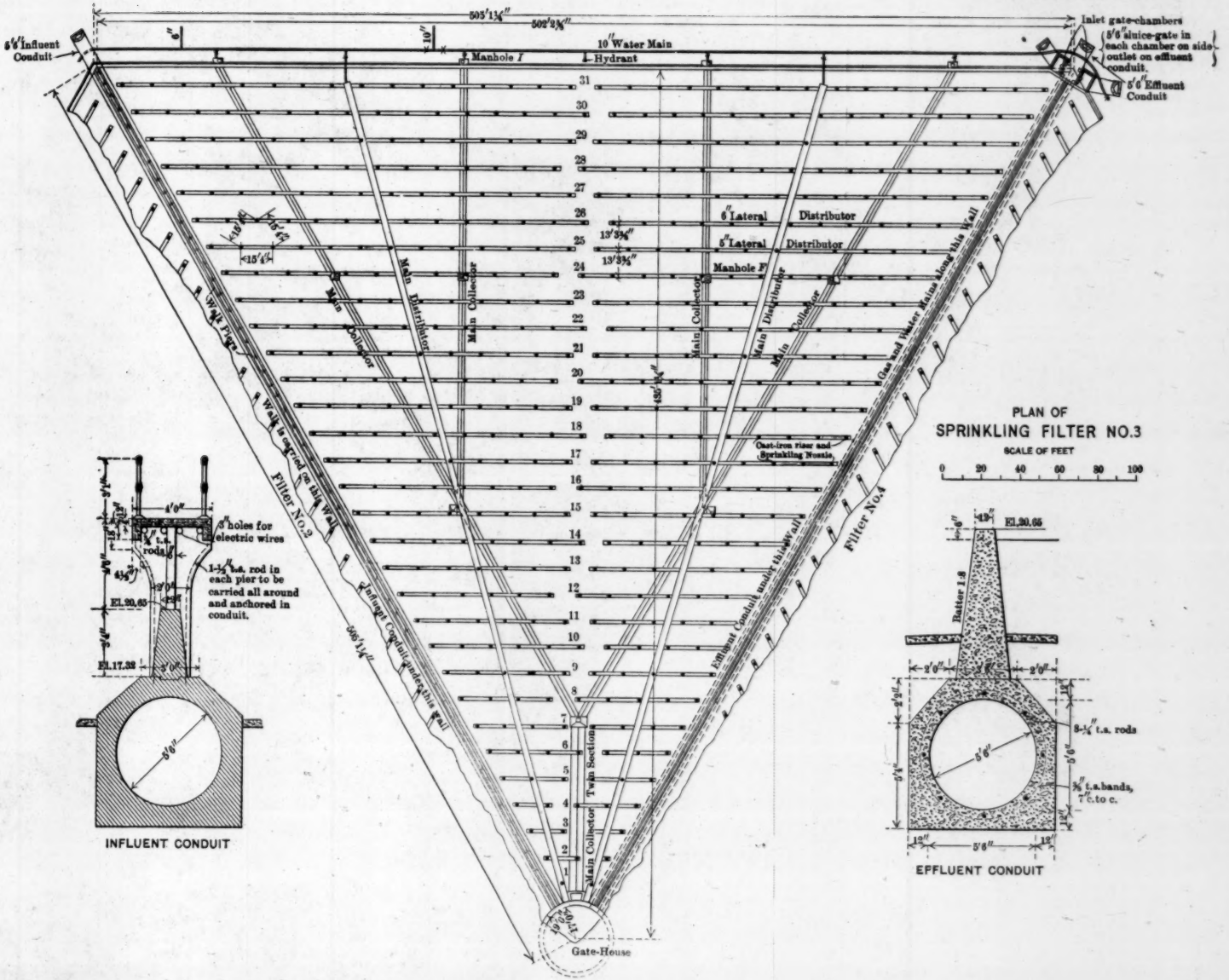
*Blow-off.*—From the east end of the collecting and distributing wall a 3 ft. 4-in. by 5-ft. blow-off conduit extends to a blow-off gate-chamber in the levee on the east side of the works, from which two blow-offs run to the river, the larger one, 4 ft. in diameter, having its outlet at the edge of the river. The smaller one, 16 in. in diameter, extends out farther, and has three outlets in the center of and at the bottom of the river. All the outlets are protected by flap-gates, and in the gate-chamber each blow-off is fitted with a sluice-gate. The 4-ft. blow-off was provided to care for a large volume of sewage which might pass over the overflow weirs in the collecting and distributing wall, and the 16-in. blow-off is for use when the tanks are drained. For the present, the sludge is disposed of in the river when the river rises and the dilution is sufficiently great, but the city has acquired a large tract of land, adjoining the works, and remote from buildings, which can be used for sludge disposal should this be found desirable or necessary at a later date.

## Gate-House.

From the center of the south wall of the septic tanks the sewage flows through a so-called influent conduit to the gate-house. This conduit, 5 ft. 6 in. in diameter, of reinforced concrete, is located under the dividing wall between Filters Nos. 2 and 3. The flow from the septic tanks and to and from the sprinkling filters is controlled at the gate-house, the details of which are shown on Plate XXVII.

*Substructure.*—The substructure of the gate-house is of concrete,

PLATE XXVIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.



heavily reinforced, and its outside diameter is 38 ft. Sewage is first admitted from the influent conduit into an influent well, 15 ft. in diameter and 25 ft. 3 in. deep, located in the center of the substructure. The influent well encloses two controller wells, approximately elliptical in plan, each 6 ft. 6 in. wide and 7 ft. long, through which the sewage flows out into an annular distributing well, 3 ft. in width, enclosing the influent well. From the distributing well the sewage passes into a series of distributing chambers connecting with the distribution systems in the filters. These distributing chambers are built in the upper portion of the outer annular well of the substructure, the lower portion being termed the effluent well, into which the effluent from the filters flows.

Each controller well contains a specially designed controller, adjustable from a minimum capacity of 10 000 000 gal. to a maximum capacity of 22 500 000 gal. per 24 hours, and operating under a minimum loss of head of about 0.75 ft.

These controllers were installed to care for the fluctuating head in the septic tanks, but, on account of the change in the method of operating these tanks, with a constant level, the controllers are not at present in use. A description of them and their action, however, may be of interest.

The controller consists of a flaring tube in which a pressure disk, attached to a vertical stem, moves up and down. The rate of flow through the controller, therefore, is dependent on the annular area between the pressure disk and the flaring tube, and on the difference in head between the two sides of the disk. The upper end of the vertical stem is shouldered, and picks up successively, as it rises, a series of weights until the difference in head on the pressure disk is balanced. With a given position of the vertical stem relative to the nest of weights above, the controller maintains automatically a practically constant rate of flow, the pressure disk and stem rising as the level in the septic tanks rises, and falling as the level in the tanks falls. The rate of flow through the controller is varied by adjusting the position of the stem relative to the nest of weights.

With the quantity of sewage at present treated, only one controller ordinarily would be in service, it being set to discharge in 24 hours, as nearly as possible, the estimated quantity which would be pumped into the septic tanks during the 24 hours, but, in case the controller should be set too low and the septic tanks should fill up to the high-

water line, and the rate of flow into the tanks should then continue in excess of the quantity discharged by the controller, this excess would pass over an overflow on the influent well into the distributing well and out to the sprinkling filters, by building up a greater head on the distribution systems. This overflow is set at a lower elevation than the overflows in the septic tanks, and would come into play before sewage would pass over the overflows in the tanks and out to the river.

In case of long-continued and excessively cold weather, provision has been made to operate the sprinkling filters as contact filters, if so desired. Under such conditions, the distribution systems would be shut off and drained, and the filters would be filled from below through by-pass gates and pipes leading from the distributing well, as may be seen by referring to Plate XXVII. The main effluent gate of each filter, of course, would be closed while the filter was filling, and opened slowly during the period of draining. It is also possible to by-pass the filters entirely by shutting the outlet gates from the distributing well and opening the gates connecting the distributing well directly with the effluent well.

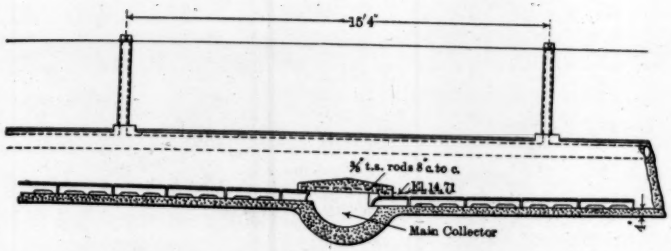
*Superstructure.*—The superstructure of the gate-house is also circular in plan, and is two stories in height. In the lower story are located the various stands for operating the sluice-gates and controllers, a chart recorder for showing the level in the septic tanks, an indicator for showing the head on the sprinkling nozzles in the filters, and a secondary indicator and chart recorder for giving the rate of flow through the 48-in. Venturi meter at the main sewage pumping station and thus through the force main into the septic tanks. The second story is divided into an office, chemical and bacteriological laboratories, a locker-room, and a lavatory containing a shower bath and sanitary conveniences. The character of the construction of the superstructure is similar to that of the superstructure of the main building at the water purification works, previously described.

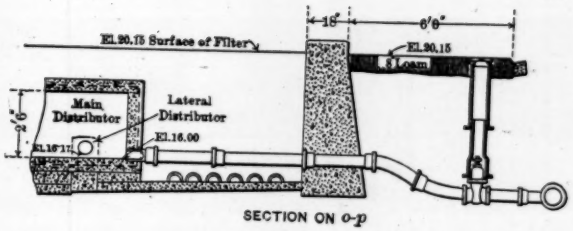
## Sprinkling Filters.

There are four sprinkling filters, radiating from the gate-house, each being an equilateral triangle in plan, 505 ft. 1¼ in. on a side. With the construction of two additional filters, space for which has been reserved, they will form a hexagon with the gate-house at the center. Each filter has a net area of 2½ acres, making a total of 10

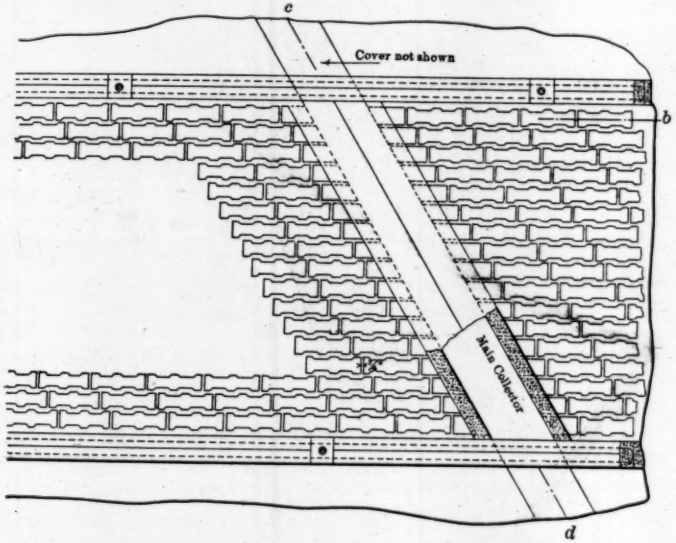
PLATE XXIX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

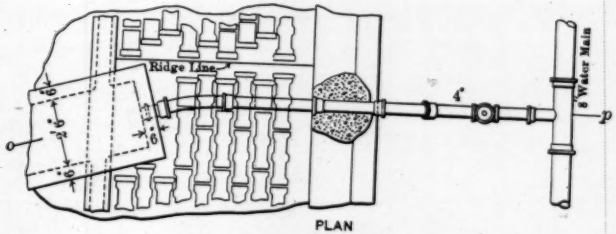
# DETAILS OF SPRINKLING FILTERS



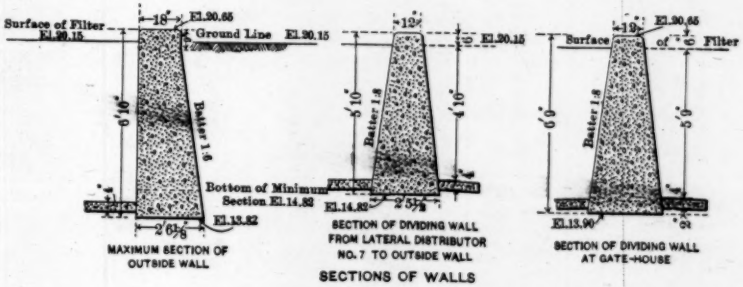

SECTION ON *o-p*




PLAN

DETAIL AT END OF MAIN DISTRIBUTOR

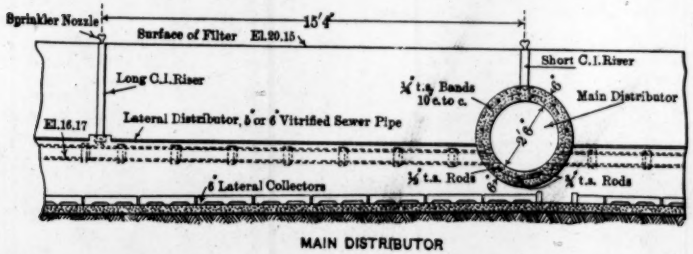



MAXIMUM SECTION OF OUTSIDE WALL

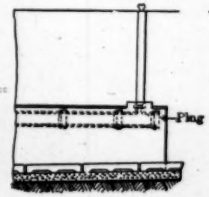
SECTION OF DIVIDING WALL FROM LATERAL DISTRIBUTOR NO. 7 TO OUTSIDE WALL

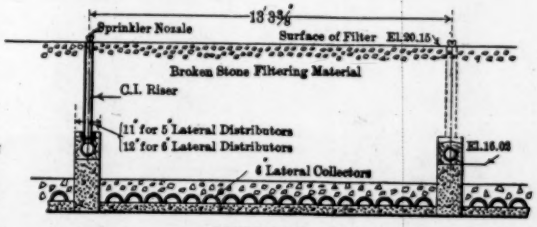
SECTION OF DIVIDING WALL AT GATE-HOUSE

SECTIONS OF WALLS

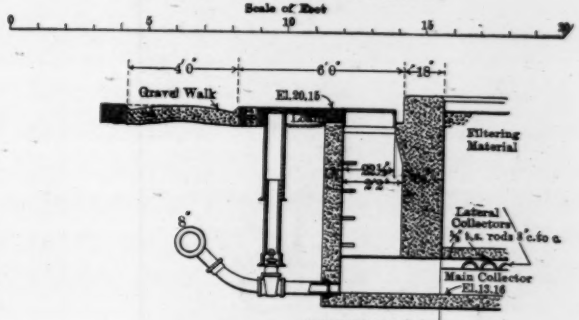



MAIN DISTRIBUTOR

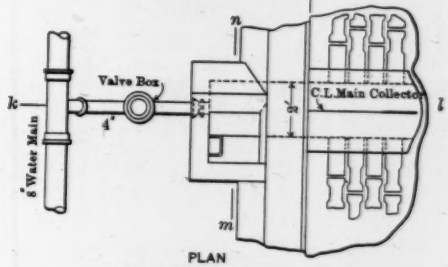



SECTION ON *e-f*



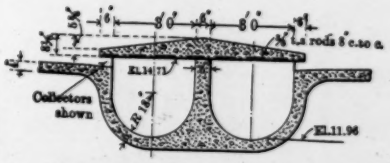

SECTION ON *k-l*




PLAN

DETAIL OF END OF MAIN COLLECTOR

MINIMUM SECTION OF MAIN COLLECTORS




MAXIMUM SECTION OF MAIN COLLECTORS

acres for all four, but, as the distribution system in each filter has been designed so that one-half of the filter can be operated independently of the other half, the present installation, from the standpoint of operation, may be considered as consisting of eight filters of 1¼ acres each.

The filters are designed to yield normally 2 000 000 gal. per acre per 24 hours, resting one-half of the time, requiring therefore a rate of 4 000 000 gal. per acre per 24 hours when in service. It is possible, however, to operate them at somewhat higher rates. The details of the filters are shown on Plates XXVIII and XXIX.

*Walls.*—The outside and dividing walls are of concrete, and were designed simply as light retaining walls and not to resist water pressure on one side with no filtering material on the other. To provide access to the gate-house, so that it can be reached when the two additional filters are constructed, without having to walk across the surface of the filters, an elevated reinforced concrete walk has been built above and is supported on the dividing wall between Filters Nos. 2 and 3.

*Distribution System.*—In order to provide protection from the frost, the distribution system is built below the surface of the filters, and consists of main distributors, lateral distributors, vertical risers, and sprinkling nozzles. The main distributors, of which there are two in each filter, are of reinforced concrete, 2 ft. 6 in. in diameter, and radiate from the gate-house. Connecting with the main distributors are the lateral distributors, which consist of lines of 5-in. and 6-in. vitrified sewer pipe supported by and bedded in the upper part of small concrete walls. From outlets in the top of the main distributor, and from sewer pipe branches set vertically in the lateral distributors, 3-in. cast-iron risers extend to the surface of the filters, the sprinkling nozzles being screwed into the upper ends of the risers. The joint at the base of each riser is made with lead caulked into the vitrified pipe socket. The distribution system in each filter is designed so that when shut off it can be drained out back to the gate-house.

The sprinkling nozzles are 15 ft. 4 in. from center to center, the arrangement being such that the straight lines connecting three adjacent nozzles form the sides of an equilateral triangle. The nozzle, Fig. 17, is of brass, and consists of a single orifice, $\frac{9}{16}$ in. in diameter, with rounded edges, above which, held by two thin arms, there is an inverted 90° cone, the axis of the cone coinciding with the axis of the

orifice. The jet, on leaving the orifice, impinges against the cone and is transformed into a thin sheet, spreading out radially and breaking into a shower of fine drops. At the points where the sheet strikes the arms, the latter are ground down to sharp edges on each side in order to permit the sheet to heal up after passing them. When the filters are operating at a rate of 4 000 000 gal. per acre per 24 hours, each nozzle will discharge approximately 13.1 gal. per min. under a head of 5 ft. available at the nozzle. There are 2 108 nozzles in the 10 acres of filter surface, about 211 nozzles per acre, the area tributary to each nozzle being 206.6 sq. ft.

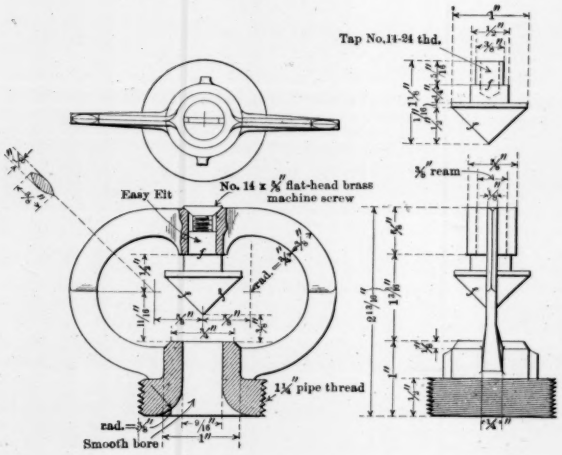



FIG. 17.

The experimental investigation at the testing station demonstrated that satisfactory results could be obtained when operating nozzles under a constant head, and the works were designed with this in view, but it has since been found that better results are obtained if the head is allowed to fluctuate, and the filters are now operated in that manner, the head on the nozzles being varied from hour to hour by hand, by throttling the sluice-gates in the gate-chamber. Modifications in the gate-house are being contemplated whereby the head will be made to fluctuate automatically.

PLATE XXX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

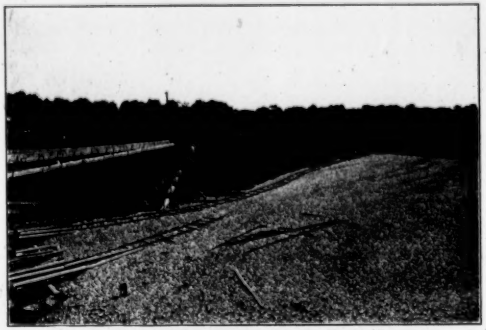


FIG. 1.—VIEW OF SPRINKLING FILTER NO. 1, LOOKING TOWARD SITE OF GATE-HOUSE.

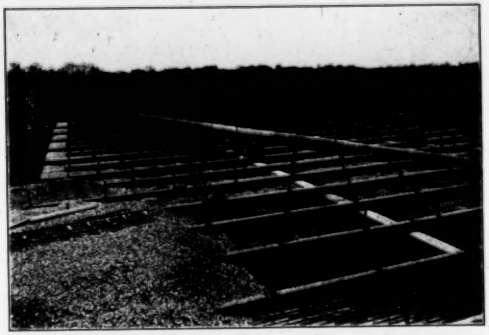


FIG. 2.—SPRINKLING FILTERS: MAIN AND LATERAL DISTRIBUTORS.

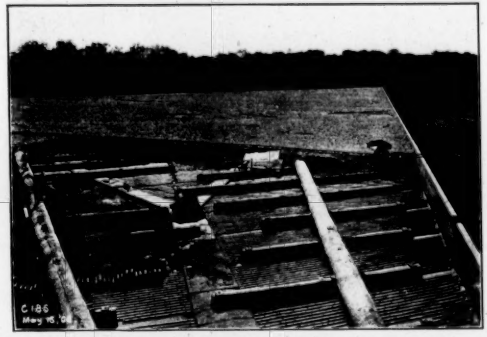



FIG. 3.—SPRINKLING FILTERS: MAIN DISTRIBUTORS AND MAIN COLLECTORS IN FOREGROUND.

FIG. 4.—VIEW OF SPRINKLING FILTERS NOS. 1 AND 2, DURING CONSTRUCTION.

*Filtering Material.*—The filtering material consists of broken stone having a total average depth of about 5 ft. 4 in., the lower 10 in. being from 3 to 4 in. in size. In Filters Nos. 1 and 2 the material above the lower course has a nominal size of from 1½ to 3 in. The material was sampled carefully from time to time, and mechanical analyses were made from which it was found that the effective size was 1.4 in. and the uniformity coefficient 1.4, and that the average size of the stone was 1.7 in., that being the diameter of a sphere of equal volume. In Filters Nos. 3 and 4 the material has a nominal size of from 1 to 3 in., an effective size of 1.1 in., a uniformity coefficient of 1.6 in. and an average size of 1.5 in. The material is all limestone, obtained partly from quarries near Columbus and partly from Marion, Ohio, and was screened at the quarries to remove the dust and fine particles and to obtain material of the right size.

*Collection System.*—For removing the effluent from the filters, a very free-draining bottom has been provided, consisting of lateral collectors discharging directly into main collectors. The lateral collectors are 6-in. vitrified channel pipe, with the sockets left off, notched on both edges, and laid in parallel lines, a space of ¾ in. being left between each two pipes longitudinally. The floors of the filters, which slope to the main collectors, are of concrete, 4 in. thick, the edges of the lateral collectors being bedded on the floor before the concrete had obtained its initial set.

The main collectors, which are of concrete, below the level of the floor of the filters, have a semicircular invert with vertical sides above and gradually increase in section toward the gate-house. The flow line is below the level of the filter floor, so that the ends of the lateral collectors will not be submerged. The main collectors in each filter discharge into a common sump and thence into the effluent well in the gate-house, the flow line in the sump being below the level of the invert of the lower end of the main collectors, so that when a main collector is not in use it will drain out completely. Manholes furnish access to the main collectors, for inspection.

## Settling Basins and Outfall.

From the substructure of the gate-house the effluent from the sprinkling filters flows through a so-called effluent conduit, to an inlet gate-chamber, then through the gate-chamber and through two inlet

conduits to the settling basins. The effluent conduit is of reinforced concrete, is 5 ft. 6 in. in diameter, and is located under the dividing wall between Filters Nos. 3 and 4.

*Inlet Gate-Chamber and Conduits.*—The inlet gate-chamber is of concrete, and is all below the surface of the ground; that part in connection with the effluent conduit is heavily reinforced. The flow from the effluent conduit is controlled by two 5½-ft. sluice-gates. The inlet conduits are also 5½ ft. in diameter, and are of concrete but are not reinforced. The sewage is admitted from the inlet conduit into each settling basin through fifteen 21-in. vitrified sewer pipe inlets terminating in a low wall.

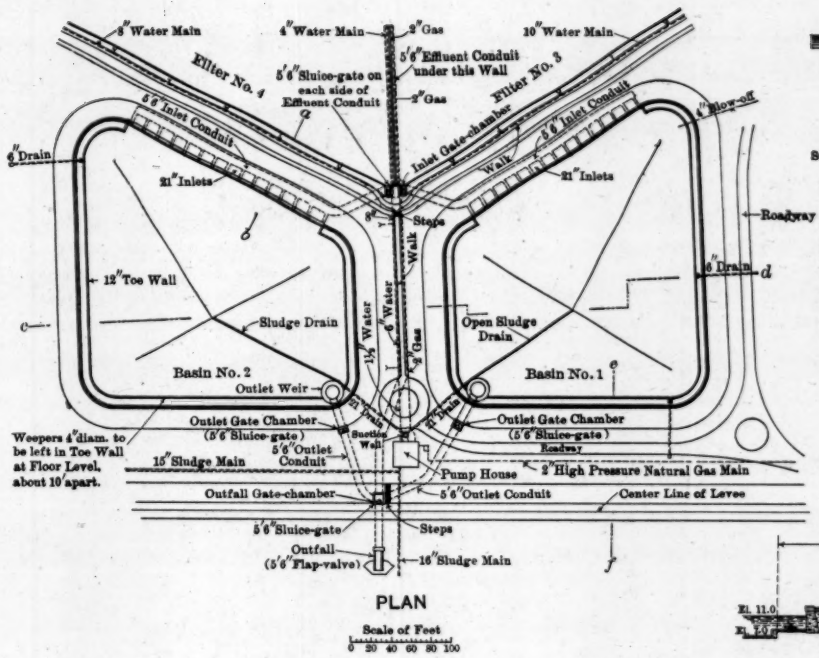
*Settling Basins.*—The effluent from the sprinkling filters is not perfectly clear, and, to remove the heavier particles in suspension, it is at times allowed to flow through one or both settling basins before passing out to the river. Each settling basin has a capacity of 2 000 000 gal., and, with one basin in use, and when handling 20 000 000 gal. of sewage per 24 hours, the average period of flow through the basin would be a little less than 2½ hours. The basins are from 4 to 4½ ft. deep, the water line being at Elevation 11.0, about 5 ft. above mean low water in the river.

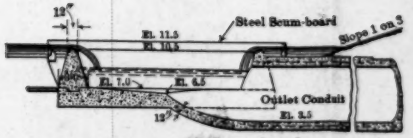
The basins are not covered, and are all in excavation. As originally built, the side slopes were 3 horizontal to 1 vertical, and were not paved or otherwise protected, except that above the water line the slope was grassed; the berm at the foot terminated at a low toe-wall, 12 in. high. On account of lack of funds, when the works were designed, it was decided to omit retaining walls around the sides of the basins, but, funds having become available since the works were completed, the retaining walls were built during the summer of 1909. The floors are of concrete, 4 in. thick, and simply provide a suitable surface for the flushing out of sludge. No attempt has been, or will be, made to exclude ground-water, on the contrary, weep-holes, 4 in. in diameter and 10 ft. apart, have been left in the toe-wall, so as to admit ground-water and prevent an upward water pressure on the floor.

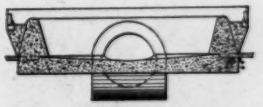
The effluent from each settling basin flows off in a thin sheet over a circular outlet weir, 19 ft. in diameter, floating matter being held back by an easily removable sheet-steel scum-board.

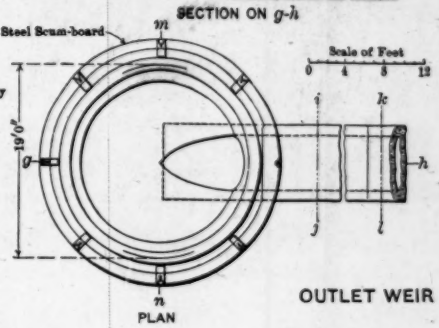
The details of the settling basins are shown on Plate XXXI.

PLATE XXXI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

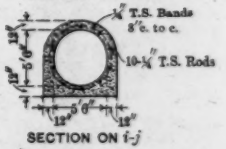


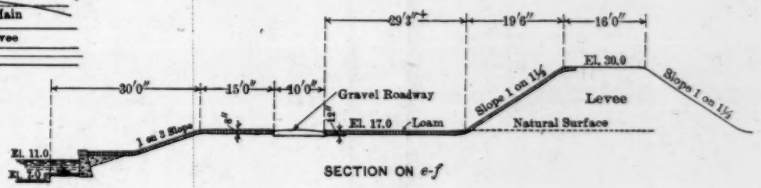



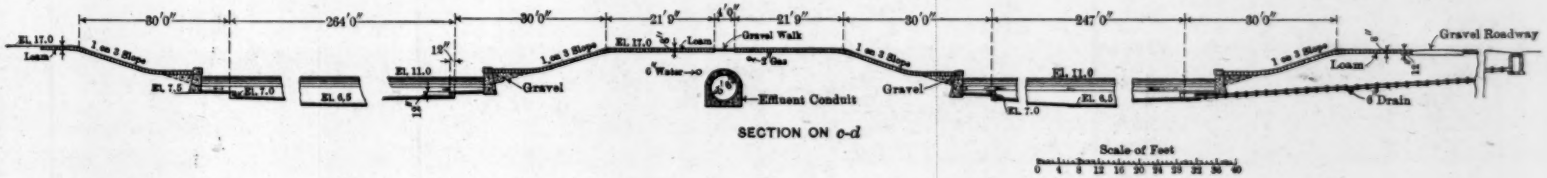



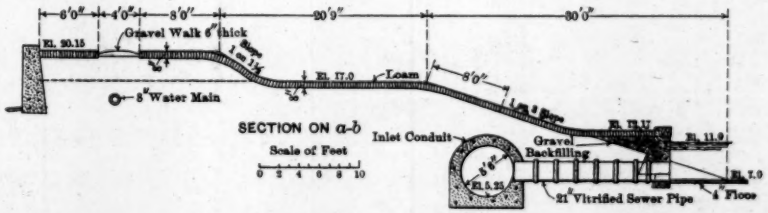

OUTLET WEIR






Scale of Feet
0 4 8 12 16 20 24 28 32 36 40




SETTLING BASINS

*Outlet Conduits and Outfall.*—From the outlet weirs the effluent from the settling basins flows through the outlet conduits to the outfall gate-chamber and thence to the outfall on the bank of the river. The outlet conduits are 5½ ft. in diameter, and are of reinforced concrete. On each of these conduits there is an outlet gate-chamber containing a 5½-ft. sluice-gate, so that either or both basins may be shut off when desired. At the outfall a 5½-ft. flap-gate has been provided, and, in the outfall gate-chamber, there is a sluice-gate of the same size, for use in case the flap-gate should fail to seat tightly during high water in the river, when it might be desired to shut down the works. From the inlet gate-chamber the effluent conduit is extended to the outfall gate-chamber, and serves as a by-pass around the settling basins, by closing the gates in the inlet and outlet gate-chambers.

Pump-House and Connections.

For the present the sludge accumulating in the settling basins is disposed of by discharging it into the river when the river rises and the dilution is great, the same as the sludge from the septic tanks. At such times the settling basins will not drain to the river, but must be pumped out, and, for this purpose, a small suction well and pump-house, the details of which are shown on Plate XXXIII, have been built at the east end of the embankment dividing the two settling basins.

*Suction Well.*—The suction well, located just outside the pump-house, is a small concrete structure, 5 ft. 6 in. in diameter and 15 ft. 7 in. deep, and into this the sludge drain in each settling basin discharges through a 21-in. pipe. From the well two 12-in. suction pipes extend into the substructure of the pump-house.

*Pumping Machinery.*—The pumping machinery consists of a horizontal, Worthington, volute pump, with 12-in. suction and 10-in. discharge nozzles, driven, through a silent-running high-speed chain, by a 50-b.h.p., vertical, enclosed, three-cylinder, Nash, gas engine, running on natural gas having a thermal value of about 1 000 B. t. u. per cu. ft. The unit has a capacity of 3 000 gal. per min. against a head of 14 ft., and 2 000 gal. per min. against a head of 26 ft., when pumping a mixture weighing 75 lb. per cu. ft. For the present, only one pumping unit has been installed, but space in the building has been provided so that the equipment may be duplicated.

*Building.*—The superstructure of the building is 23 ft. 6 in. square inside, is one story high, and is of the same character of construction

as the superstructure of the gate-house. The substructure is of concrete.

*Sludge Mains.*—Outside of the building the discharge pipe from the pump branches into two sludge mains, one 16 in. and the other 15 in. in diameter. The 16-in. main extends out into the river, with outlets below the surface, being a duplicate of the blow-off used for draining sludge from the septic tanks. The 15-in. main terminates at present at the site of the garbage reduction works. When the sewage purification works were designed, it was not expected that the garbage disposal works would be located adjacent to the sewage purification works, and the levee was built in a position other than that shown on Plate XXIII, with the 15-in. main terminating outside of the levee. This main was laid so that, if disposal of the sludge from the settling basin on land was found desirable, an outlet would be provided. In the fall of 1908 a portion of the levee in the southeast corner of the works was moved so as to provide a site for the reduction works, but the sludge main will not be extended until after the reduction works are built; its final location will then be determined.

## Miscellaneous.

*Water Main.*—In the main and lateral distributors and in the main collectors of the filters, in order to keep the friction losses low, it was necessary to use depositing velocities. To provide means for flushing these out in case of deposition, a water main has been laid with a branch connecting directly with the outer end of each main distributor and each main collector. To flush out the lateral distributors, the nozzle in the riser at the outer end of each distributor would be removed and a hose connection made with one of the hydrants placed along the outside walls of the filters. Hydrants have also been placed adjacent to the septic tanks and settling basins, so that an ample supply of water under pressure may at all times be obtained for flushing purposes.

*Loss of Head.*—The total loss of head through the works, from high-water line in the primary septic tanks to mean low water in the river, is 25.34 ft., and, without giving all the individual losses through gates, conduits, etc., may be summarized as given in Table 13. It should be stated that the losses are computed on the basis of the works handling a maximum quantity of 45 000 000 gal. per 24 hours.

PLATE XXXII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1146.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

FIG. 1.—VIEW OF SPRINKLING FILTER NO. 2.

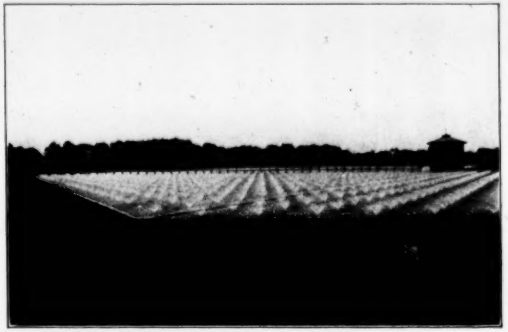


FIG. 2.—VIEW OF SPRINKLING FILTERS NOS. 1 AND 2.

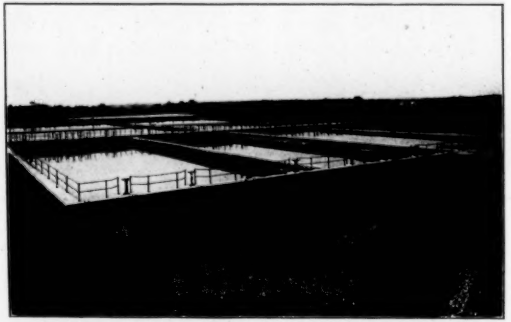


FIG. 3.—VIEW OF SEPTIC TANKS, FROM NORTH END.

TABLE 13.—Loss of Head Through Works.

| Location. | Elevation, in feet above city datum. | Loss of head, in feet. |
|---|---|---|
| High-water line, primary septic tanks | 31.34 | ... |
| Low-water line, primary septic tanks | 28.24 | 3.10 |
| Hydraulic grade at sprinkling nozzles | 25.15 | 3.09 |
| Surface of filter | 20.15 | 5.00 |
| Hydraulic grade, lower end of main collector | 13.77 | 6.38 |
| Hydraulic grade, effluent well in gate-house | 11.96 | 1.81 |
| Water line, settling basins | 11.00 | 0.96 |
| Mean low water in river | 6.00 | 5.00 |
| Total | .... | 25.34 |

*Operation During Freshets.*—With a 5-ft. rise in the river, the settling basins would be shut off, but the filters could still be operated under normal conditions. With a total rise of 7 ft. in the river the filters would cease to be free-draining at the bottom, and would probably be shut off. It would be possible, however, still to operate the filters with a greater rise than 7 ft. in the river by allowing them to fill up with sewage sprayed on from the sprinkling nozzles until the filters were full up to the surface. Whether or not this method of operation would be satisfactory can only be determined by trial. At the best, however, operation at such times would require the most careful supervision, as the river may easily rise at the rate of 0.75 ft. per hour, and, unless the filters were shut off at the proper time, the outside walls would be overflowed. Again, if, for any reason, the flap-gate at the main outfall should become deranged at such a time, the river, which is highly turbid during freshets, might back up into the filters and deposit a large amount of mud, a result which would be simply disastrous, as in all probability the stone would have to be removed from the filters and washed, and the filters themselves would have to be cleaned and washed out. Assuming, however, that the filters are shut off with a 7-ft. rise in the river, the septic tanks can still be operated, even up to maximum high water in the river, the effluent from the tanks flowing to the gate-house, through the by-pass between the influent and effluent wells, and then out through the effluent conduit directly to the river.

## Concrete.

In the construction of the sewage purification works, concrete, both plain and reinforced, was used extensively. The relative volumes of cement, sand, and ballast in the several classes of work were as follows:

1:2:4.—Water-tables, belt-courses, window-sills, lintels, etc.; substructure of gate-house (except foundation floor), and walk over influent conduit wall; reinforced floors, columns, stairways, and steps.

1:2½:5½.—Sprinkling filters, settling basins, collecting and distributing, and north and south walls of septic tanks; conduits and blow-offs, foundations, and miscellaneous small structures.

1:3:7.—East and west outside walls, baffle walls, and dividing walls of septic tanks (except collecting and distributing wall).

The specifications for the concrete were similar to those for the water purification works, and the method of mixing and placing the material was practically the same. The expansion joints, which were built where necessary, consisted, however, only of a tongue and groove in the concrete, no steel plates being used. The tongues and the grooves were well reinforced, both vertically and horizontally, with twisted steel rods.

### Cost of Work.

In Table 14 the cost of the work in detail is given, and in Table 15 is given the unit cost of the main features of the work. As was the case with the cost of the water-works improvements, and for the same reason, no attempt has been made to distribute the cost of engineering over the several parts of the work.

### Contractors and Progress of Work.

The first bond issue was authorized in November, 1903, and the preparation of the first drawings and specifications began early in 1904. The first work placed under contract was the testing station, in May, 1904. Additional contracts were let during 1904 and 1905, and in November, 1905, the purification works were placed under contract. The work was all practically completed by the fall of 1908, although the last contract, for the concrete walls around the settling basins, at the purification works, was not let until April, 1909. Sewage was first pumped regularly to the purification works on November 28th, 1908.

The principal contracts for the work were:

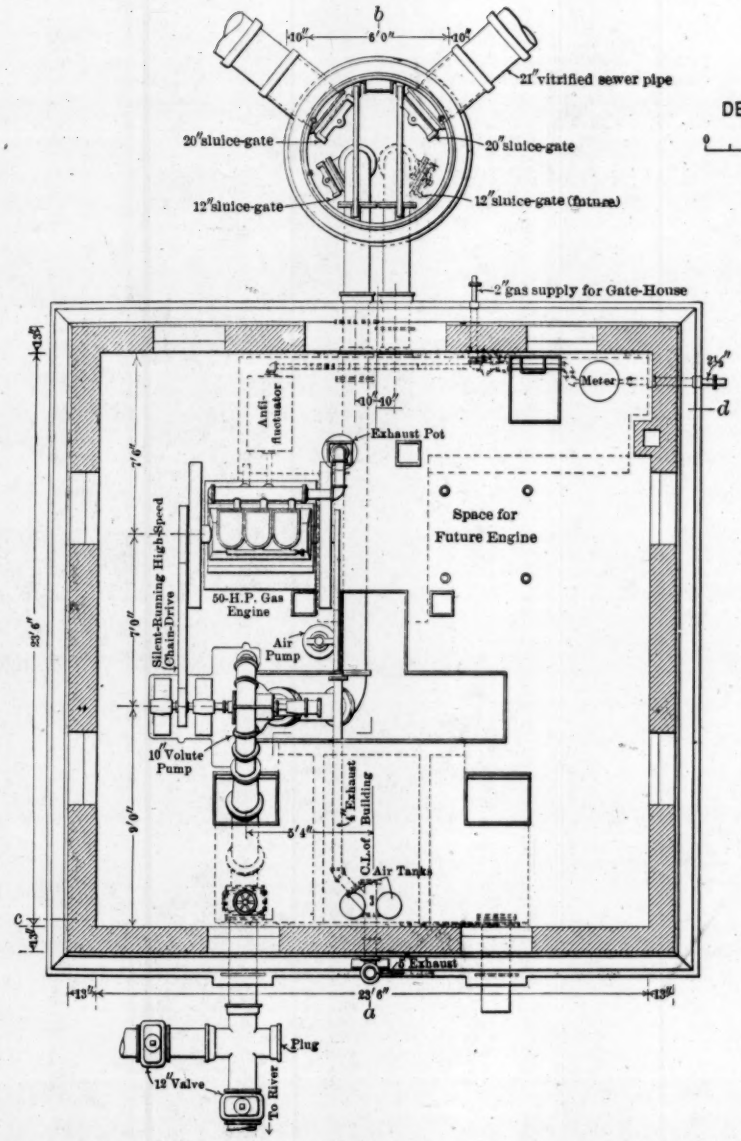
Levees and railroad spur.....The T. A. Gillespie Company and D. E. Sullivan and Son.

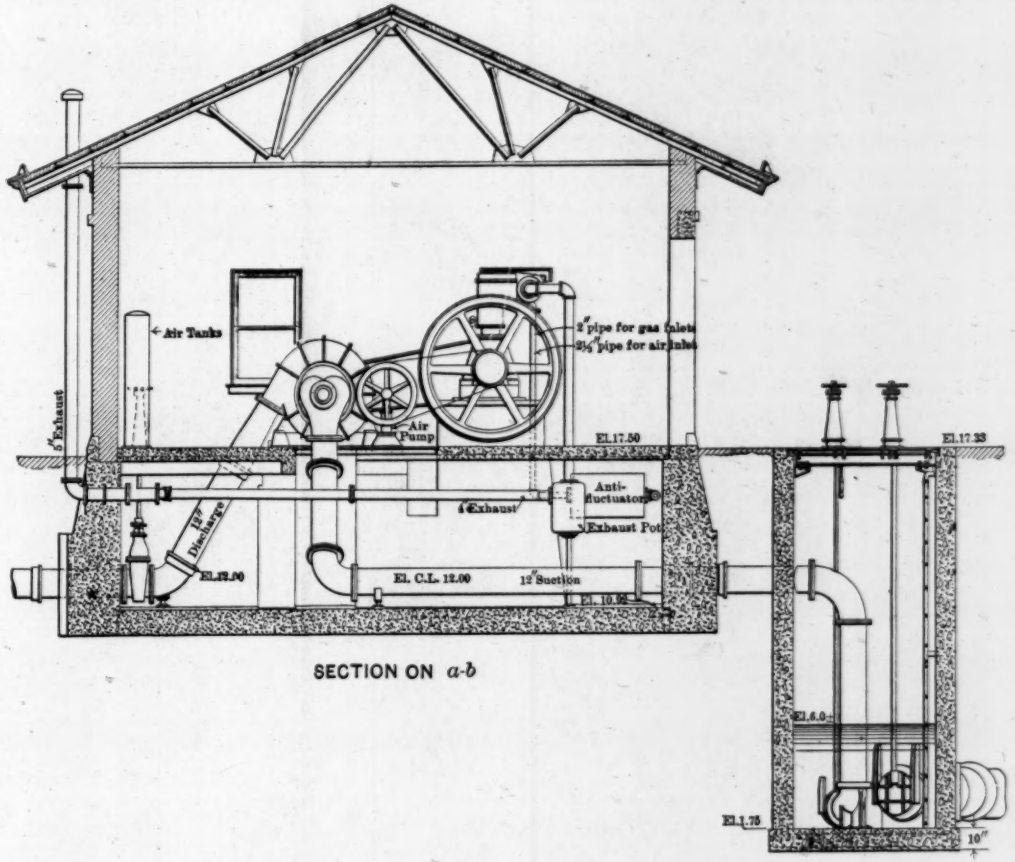
Bridge .....Cooke and Grant, and Houston and Cleveland.

PLATE XXXIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXVII, No. 1148.
GREGORY ON
IMPROVED WATER AND SEWAGE WORKS
AT COLUMBUS, OHIO.

# DETAILS OF PUMP-HOUSE

SCALE OF FEET




SECTION ON *a-b*

Sewers ..... Westwater and Casey, and C. T. McCracken and Company.
Sewage force mains..... Westwater and Casey, and The York Construction Company.
Pumping stations..... Westwater and Casey, and D. W. McGrath.
Pumping machinery..... Woollen and Callon, and Columbus Machine Company.
Sewage screens and sluice-gates..Coffin Valve Company.
Sewage purification works.....Sullivan, Murphy and Miles, and D. E. Sullivan and Son.

## Operation.

The daily records of the results of operation of the sewage purification works for the eight months, January to August, 1909, inclusive, are presented in Table 16. As it is through the courtesy of the Engineer and Chief Chemist of the works that the writer is enabled to present these results, he will not enter into a detailed discussion of them, but hopes that such a discussion will be presented by these officials.

In order that the efficiency of the works may be judged, there is presented in Table 17 the final averages of the results obtained in the experimental investigation with Test Filter *C*, this filter having given the best results of those experimented with at the testing station.

From an examination of the data in these two tables it will be noted that during the earlier part of the period of operation the results secured at the purification works were much below normal, due largely, among other factors, to the unusually strong sewage, and especially to the fact that the filters were started at the most unfavorable time of the year, that is, just at the beginning of cold weather, and therefore had been afforded no opportunity to ripen.

With the advent of warmer weather, however, a steady improvement in the character of the results began, and from an examination of the later results secured at the works it will be seen that they compare very favorably with the results obtained with Test Filter *C*, thus demonstrating that the works serve, in a satisfactory manner, the purpose for which they were designed. The writer has but one comment to add, and that is, from such information as he can secure, it would

## TABLE 14.—Cost of Sewage Improvements.

| | | | | |
|---|---|---|---|---|
| **East Side Sewage Pumping Station and Force Main.** | | | | |
| Land.....2 acres | | | $3 500 | |
| Roads, Walks, Grading, and Drainage of Grounds. | | | | |
| Roads, walks and grading | | $1 810 | | |
| Drainage of grounds | | 160 | 1 970 | |
| Sewer, Gas, Water, and Electric Connections. | | | | |
| Sewer connections | | 1 260 | | |
| Gas supply connection | | 170 | | |
| Water supply connection | | 80 | | |
| Electric connections | | 120 | 1 630 | |
| Pumping Station. | | | | |
| Building. | | | | |
| Substructure | $6 330 | | | |
| Superstructure.....25 700 cu. ft. | 5 480 | 11 810 | | |
| Machinery and Equipment. | | | | |
| Screening equipment | 540 | | | |
| Centrifugal pumps and gas engines....2 | 9 480 | | | |
| Piping and appurtenances for engines.. | 1 050 | | | |
| Suction and discharge piping | 1 950 | | | |
| Miscellaneous equipment | 40 | 13 060 | 24 870 | |
| 20-in. Sewage Force Main. | | | | |
| 20-in. Venturi meter | | 1 530 | | |
| 20-in. force main.....8 120 lin. ft. | | 37 030 | | |
| Manholes | | 1 930 | | |
| 20-in. blow-off and manhole at pumping station | | 920 | 41 410 | $73 380 |
| **Levees and Railroad Spur to Main Sewage Pumping Station and Sewage Purification Works.** | | | | |
| Land.....65 acres | | | 15 580 | |
| Levees.....9 780 lin. ft. | | | | |
| From Hocking Valley Railway to bridge.....1 270 lin. ft. | | 8 880 | | |
| From bridge to pumping station lot.....1 800 lin. ft. | | 10 830 | | |
| On river side of pumping station lot.....860 lin. ft. | | 12 590 | | |
| From pumping station lot to purification works.....5 850 lin. ft. | | | | |
| Levee | 23 880 | | | |
| Culverts.....458 lin. ft. | 4 380 | 28 260 | 60 560 | |
| Bridge. | | | | |
| Substructure. | | | | |
| Earthwork | 1 740 | | | |
| Timber piling | 2 250 | | | |
| Concrete piers and abutments | 10 490 | 14 480 | | |
| Superstructure. | | | | |
| Steelwork.....785 200 lb. | 42 070 | | | |
| Timber bridge floor.....460 lin. ft. | 930 | 43 000 | 57 480 | |
| Railroad Track.....9 760 lin. ft. | | | | |
| From Hocking Valley Railway to bridge.....1 250 lin. ft. | | 2 990 | | |
| On bridge.....460 lin. ft. | | 430 | | |
| From bridge to pumping station.....1 830 lin. ft. | | 3 860 | | |
| At river side of pumping station. 620 lin. ft. | | 1 300 | | |
| From pumping station to purification works.....5 600 lin. ft. | | 11 810 | 20 390 | 154 010 |
| Carried forward..... | | | | $227 390 |

TABLE 14.—(*Continued.*)

| | | | | |
|---|---|---|---|---|
| Brought forward | | | | $227 390 |
| ADDITIONAL LEVEE CONSTRUCTION. | | | | |
| Land, 26 acres | | | $8 760 | |
| Levee north of bridge, 2 450 lin. ft. | | | 10 260 | |
| Levee south of purification works | | | 820 | 19 840 |
| GRAVEL ROAD FROM MAIN SEWAGE PUMPING STATION TO SEWAGE PURIFICATION WORKS | | | | 1 620 |
| RECONSTRUCTION OF SEWERS IN WEST SIDE DISTRICT | | | | 16 090 |
| ENLARGING AND REGRADING RENICK RUN DITCH, 4 020 lin. ft. | | | | 7 080 |
| WATER AND GAS MAIN EXTENSIONS. | | | | |
| 10-in. Water Main. | | | | |
| From High Street to pumping station, 4 550 lin. ft. | | $8 080 | | |
| From pumping station to purification works, 6 400 lin. ft. | | 8 870 | 16 950 | |
| 2-in. high-pressure gas main from Stimmel Road to purification works, 8 760 lin. ft. | | | 1 740 | 18 690 |
| SEWER EXTENSIONS TO MAIN SEWAGE PUMPING STATION LOT. | | | | |
| 48-in. Intercepting Sewer. | | | | |
| Land, 1 acre | | 140 | | |
| Relief outlet | | 1 570 | | |
| Extension of 48-in. sewer, 540 lin. ft. | | 10 370 | 12 080 | |
| West Side Sewers. | | | | |
| Land, 2 acres | | 1 500 | | |
| West Side sanitary and Renick Run storm-water sewers | | 115 490 | 116 990 | 129 070 |
| WORK AT MAIN SEWAGE PUMPING STATION LOT. | | | | |
| Levee around lot, 1 230 lin. ft. | | | 7 870 | |
| Roads, Walks, Grading, and Drainage of Grounds. | | | | |
| Roads, walks, and grading | | 2 350 | | |
| Drainage of grounds | | 950 | 3 300 | |
| Railroad siding north and south of coal pocket, 560 lin. ft. | | | 1 230 | |
| Connection to water main | | | 180 | |
| Sewers, connections and outlets to river | | | 40 480 | |
| Force Main Connections. | | | | |
| To 48-in. sewage force main | | 1 150 | | |
| To 48-in. storm-water force main | | 1 390 | 2 540 | |
| 48-in. storm-water force main to river, 270 lin. ft. | | | 2 960 | 58 560 |
| MAIN SEWAGE PUMPING STATION. | | | | |
| Building, 358 800 cu. ft. | | | | |
| Substructure, 110 200 cu. ft. | | 25 710 | | |
| Superstructure, 248 600 cu. ft. | | 29 010 | 54 720 | |
| Chimney. | | | | |
| Substructure, 13 ft. deep | | 1 400 | | |
| Superstructure, 5 ft. diam., 130 ft. high | | 3 300 | 4 700 | |
| Machinery and Equipment. | | | | |
| Screening equipment and press | | 17 970 | | |
| Engine-driven centrifugal pumps, large units, 3 | | 12 670 | | |
| Engine-driven centrifugal pumps, small units, 2 | | 6 030 | | |
| Electric generating units and switch-board, 2 | | 2 640 | | |
| Boilers and accessories, 450-h.p. | | 7 980 | | |
| Steel boiler flue | | 1 010 | | |
| Suction and discharge piping | | 8 610 | | |
| Steam appurtenances and piping | | 11 440 | | |
| Miscellaneous equipment | | 770 | | |
| Hand traveling crane | | 3 300 | 72 420 | 131 840 |
| Carried forward | | | | $610 180 |

TABLE 14.—(*Continued.*)

| | | | | |
|---|---|---|---|---|
| Brought forward | | | | $610 180 |
| 48-in. Sewage Force Main. | | | | |
| 48-in. Venturi meter and vault | | | $4 450 | |
| 48-in. force main, 6 370 lin. ft. | | | 76 280 | |
| 16-in. blow-off | | | 320 | 81 050 |
| Pole Line from Pumping Station to Purification Works | | | | 1 100 |
| Land for Sewage Purification Works, 262 acres | | | | 49 500 |
| Sewage Purification Works. | | | | |
| Levee (earthwork in excess of that obtained from excavations for structures), 5 100 lin. ft. | | | 10 330 | |
| Railroad spurs on levees, 1 330 lin. ft. | | | 2 500 | |
| Roads, walks, grading, and drainage of grounds | | | 3 590 | |
| 3-ft. culvert at north end of works, 310 lin. ft. | | | 2 700 | |
| Gas mains and connections | | | 490 | |
| 10-in. water main and connections | | | 6 020 | |
| Septic Tanks, 8 020 000 gal. | | | | |
| Earthwork | | $3 640 | | |
| Concrete and brick masonry | | 46 740 | | |
| Steel reinforcement | | 1 330 | | |
| Sluice-gates | | 12 530 | | |
| Iron and steelwork | | 410 | | |
| Railings | | 1 090 | | |
| Scum-boards | | 990 | 66 730 | |
| Blow-off from Septic Tanks. | | | | |
| 3 ft. 4-in. by 5 ft., from septic tanks to blow-off gate-chamber, 210 lin. ft. | | 1 830 | | |
| Blow-off gate-chamber | | 1 250 | | |
| 4-ft., from blow-off gate-chamber to main outlet, 60 lin. ft. | | 370 | | |
| Main outlet | | 1 830 | | |
| 16-in. sludge drain and river outlets, 240 lin. ft. | | 1 430 | 6 710 | |
| Walk on influent conduit wall, 490 lin. ft. | | | 1 620 | |
| 5 ft. 6-in. influent conduit from septic tanks to gate-house, 570 lin. ft. | | | 5 890 | |
| Gate-house, 61 500 cu. ft. | | | | |
| Substructure, 31 700 cu. ft. | | | | |
| Earthwork | $390 | | | |
| Concrete | 7 940 | | | |
| Steel reinforcement | 900 | | | |
| Vitrified sewer pipe | 70 | | | |
| Iron and steelwork | 710 | | | |
| Sluice-gates | 9 650 | | | |
| Controlling, indicating, and recording devices | 3 770 | 23 430 | | |
| Superstructure, 29 800 cu. ft. | | 7 620 | | |
| Furniture and Equipment. | | | | |
| Furniture and fittings | 240 | | | |
| Laboratory equipment | 1 620 | 1 860 | 32 910 | |
| Carried forward | | | $139 490 | $741 830 |

TABLE 14.—(*Continued.*)

| | | | | |
|---|---|---|---|---|
| Brought forward | | | $139 490 | $741 830 |
| SEWAGE PURIFICATION WORKS (*Continued*). | | | | |
| Sprinkling Filters.....10 acres | | | | |
| Earthwork | | $13 930 | | |
| Floors and main collectors | | 26 200 | | |
| Free draining bottom | | 34 000 | | |
| Walls.....4 440 lin. ft. | | 11 700 | | |
| Manholes.....44 | | 1 070 | | |
| Distribution System. | | | | |
| 30-in. main distributors..... 3 430 lin. ft. | $7 480 | | | |
| 5-in. lateral distributors...18 190 lin. ft. | 8 390 | | | |
| 6-in. lateral distributors.. 10 060 lin. ft. | 4 970 | | | |
| Risers and nozzles.....2 108 | 6 860 | 27 700 | | |
| Filtering material.....80 120 cu. yd. | | 125 800 | 240 400 | |
| 5 ft. 6-in. Effluent Conduit. | | | | |
| From gate-house to inlet gate-chamber.....480 lin. ft. | | 6 000 | | |
| From inlet gate-chamber to outfall gate-chamber.....800 lin. ft. | | 3 430 | | |
| Outfall gate-chamber | | 1 940 | | |
| From outfall gate-chamber to outfall..... 40 lin. ft. | | 650 | | |
| Outfall | | 2 360 | 14 380 | |
| Inlets to Settling Basins. | | | | |
| Inlet gate-chamber | | 2 340 | | |
| 5 ft. 6-in. inlet conduits.....540 lin. ft. | | 5 530 | | |
| 21-in. pipe inlets.....480 lin. ft. | | 440 | 8 310 | |
| Settling Basins .....4 000 000 gal. | | | | |
| Earthwork | | 25 620 | | |
| Concrete | | 12 160 | | |
| Iron and steelwork | | 140 | 37 920 | |
| Outlets from Settling Basins. | | | | |
| 5 ft. 6-in. outlet conduits to outlet gate-chambers.....50 lin. ft. | | 720 | | |
| Outlet gate-chambers | | 2 140 | | |
| 5 ft. 6-in. outlet conduits, from outlet gate-chambers to outfall gate-chamber.....180 lin. ft. | | 2 520 | | |
| 21-in. pipe drains to suction well..150 lin. ft. | | 340 | 5 720 | |
| Suction Well | | | 230 | |
| Pump House. | | | | |
| Building.....13 940 cu. ft. | | | | |
| Substructure.....4 040 cu. ft. | 1 020 | | | |
| Superstructure.....9 900 cu. ft. | 1 990 | 3 010 | | |
| Machinery | | 3 610 | | |
| Suction and discharge piping | | 820 | 7 440 | |
| Sludge Force Mains. | | | | |
| 16-in. main to river, including outlets.....220 lin. ft. | | 1 250 | | |
| 15-in. main to south end of works..520 lin. ft. | | 360 | 1 610 | |
| Expenses Unclassified | | | 860 | 456 350 |
| Total Cost, Exclusive of Engineering | | | | $1 198 180 |
| ENGINEERING, 8.98 per cent. | | | | |
| Pay-roll | | | 90 820 | |
| Supplies | | | 6 450 | |
| Expenses | | | 10 280 | 107 550 |
| TOTAL COST | | | | $1 305 730 |
| EXPERIMENTAL INVESTIGATION | | | | 45 290 |
| TOTAL COST, INCLUDING EXPERIMENTAL INVESTIGATION | | | | $1 351 020 |

TABLE 15.—UNIT COSTS OF MAIN FEATURES OF WORK.

| Work. | Capacity. | Total cost. | Unit costs. |
|---|---|---|---|
| Buildings. | | | |
| East Side Sewage Pumping Station. | | | |
| Superstructure | 25 700 cu. ft. | $5 480 | 21.3 cents per cu. ft. |
| Main Sewage Pumping Station. | | | |
| Substructure | 110 200 cu. ft. | 25 710 | 23.4 " " " " |
| Superstructure | 248 600 cu. ft. | 29 010 | 11.7 " " " " |
| Total | 358 800 cu. ft. | 54 720 | 15.3 " " " " |
| Gate-House, Sewage Purification Works. | | | |
| Substructure | 31 700 cu. ft. | 23 430 | 73.9 " " " " |
| Superstructure | 29 860 cu. ft. | 7 620 | 25.6 " " " " |
| Total | 61 560 cu. ft. | 31 050 | 50.5 " " " " |
| Pump House, Sewage Purification Works. | | | |
| Superstructure | 9 900 cu. ft. | 1 990 | 20.1 " " " " |
| Septic Tanks | 8 020 000 gal. | $66 730 | $8 320 per million gallons. |
| Sprinkling Filters | 10 acres | 240 400 | 24 040 per acre. |
| Settling Basins | 4 000 000 gal. | 37 920 | 9 480 per million gallons. |
| Sewage Purification Works. | | | |
| Levee, railroad spurs and culvert | 20 000 000 gal. per 24 hours | $15 530 | $780 per million gallons per 24 hours. |
| Roads, walks, grading and drainage of grounds | | 3 590 | 180 |
| Water and gas mains | | 6 510 | 330 |
| Septic tanks | | 66 730 | 3 340 |
| Blow-off from septic tanks | | 6 710 | 340 |
| Walk on influent conduit wall | | 1 620 | 80 |
| Influent conduit | | 5 890 | 290 |
| Gate-house | | 32 910 | 1 640 |
| Sprinkling filters | | 240 400 | 12 020 |
| Effluent conduit | | 14 380 | 720 |
| Inlets and outlets to settling basins | | 14 030 | 700 |
| Settling basins | | 37 920 | 1 900 |
| Pump-house and suction well | | 7 660 | 380 |
| Sludge force mains | | 1 610 | 80 |
| Expenses unclassified | | 860 | 40 |
| Total | | $456 350 | $22 820 |

TABLE 16.—SEWAGE PURIFICATION WORKS.—Records of Operation for January, 1909.

| Day of Month. | Temperature, Degrees, Fahr. | | | Rainfall, in inches. | Volume pumped, in millions of gallons per day. | Flow in septic tanks, average period, in hours. | Volume filtered, in millions of gallons per day. | Filter area in service during application of sewage, in acres. | Average rate of filtration during application of sewage, in millions of gallons per acre per day. | Flow in settling basin, average period, in hours. | Analytical Results, Parts per Million. | | | | | | | | Bacteria. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Air. | | | | | | | | | | Suspended Matter. | | | | Oxygen Consumed. | | Final Effluent. | | | | Millions per c.c. | | | |
| | Maximum. | Minimum. | Sewage. | | | | | | | | Screened sewage. | Septic effluent. | Filter effluent. | Settling basin effluent. | Screened sewage. | Septic effluent. | Dissolved oxygen. | Putrescibility (odor) incubated 24 hrs. @ 37° C. | Nitrites. | Nitrates. | Screened sewage. | Septic effluent. | Filter effluent. | Settling basin effluent. |
| 1 | 30 | 16 | 56 | 0.00 | 9.52 | 11.6 | 9.52 | 2.50 | 3.80 | 10.0 | 224 | 77 | .... | 36 | 110 | 44 | 4.8 | N | 0.12 | 0.60 | 3.08 | 0.64 | 0.46 | 1.06 |
| 2 | 38 | 21 | 56 | 0.00 | 11.01 | 10.0 | 11.01 | 2.85 | 3.86 | 9.0 | 376 | 89 | .... | 37 | 86 | 45 | 4.4 | ? | 0.12 | 0.52 | 1.84 | 1.00 | 0.88 | 0.84 |
| 3 | 49 | 36 | 55 | 0.01 | 10.83 | 10.0 | 10.83 | 2.80 | 3.86 | 9.0 | 252 | 112 | .... | 41 | 97 | 44 | 3.1 | ? | 0.11 | 0.49 | 4.50 | 0.64 | 0.40 | 1.20 |
| 4 | 56 | 44 | 56 | 0.21 | 14.82 | 7.5 | 14.82 | 3.25 | 4.56 | 6.5 | 1 088 | 138 | .... | 39 | 192 | 72 | 3.5 | P | 0.14 | 0.58 | 1.50 | 1.12 | 1.10 | 0.90 |
| 5 | 53 | 37 | 56 | 0.17 | 16.40 | 6.7 | 16.40 | 3.95 | 4.15 | 5.8 | 740 | 160 | .... | 81 | 136 | 65 | 4.3 | P | 0.07 | 0.36 | 1.25 | 1.00 | 1.10 | 1.00 |
| 6 | 37 | 10 | 56 | 0.02 | 11.82 | 9.3 | 11.82 | 3.12 | 3.96 | 8.0 | 268 | 124 | .... | 66 | 94 | 62 | 3.7 | ? | 0.05 | 0.51 | 2.35 | 0.94 | 1.00 | 1.40 |
| 7 | 21 | 10 | 55 | tr. | 12.20 | 9.0 | 12.20 | 3.12 | 3.91 | 8.0 | 220 | 108 | .... | 54 | 79 | 57 | 3.4 | N | 0.04 | 0.31 | 2.70 | 1.10 | 1.00 | 1.10 |
| 8 | 30 | 16 | 55 | 0.00 | 11.70 | 9.4 | 11.70 | 3.05 | 3.84 | 8.0 | 232 | 90 | .... | 44 | 102 | 62 | 3.1 | ? | 0.07 | 0.36 | 3.00 | 0.80 | 0.56 | 0.80 |
| 9 | 41 | 29 | 56 | 0.02 | 11.20 | 10.0 | 11.20 | 3.12 | 3.60 | 8.5 | 218 | 108 | .... | 38 | 94 | 56 | 3.2 | P | 0.10 | 0.30 | 1.10 | 1.38 | 0.92 | 0.92 |
| 10 | 51 | 39 | 56 | 0.04 | 10.26 | 10.0 | 10.26 | 2.80 | 3.66 | 9.3 | 442 | 106 | .... | 46 | 121 | 55 | 3.0 | P | 0.12 | 0.27 | 5.30 | 1.00 | 1.32 | 1.34 |
| 11 | 31 | 20 | 56 | 0.22 | 13.24 | 7.6 | 13.24 | 3.12 | 4.62 | 6.6 | 302 | 100 | .... | 70 | 115 | 66 | 3.5 | ? | 0.15 | 0.75 | 4.95 | 0.70 | 1.02 | 0.80 |
| 12 | 14 | 10 | 56 | 0.17 | 13.33 | 7.6 | 13.33 | 2.92 | 4.98 | 6.6 | 252 | 86 | .... | 56 | 108 | 71 | 4.0 | N | 0.07 | 0.76 | 2.80 | 1.14 | 1.00 | 0.70 |
| 13 | 23 | 6 | 54 | 0.30 | 14.74 | 6.8 | 14.74 | 3.40 | 4.32 | 6.5 | 270 | 108 | .... | 64 | 95 | 62 | 3.7 | N | 0.23 | 0.42 | 2.72 | 0.88 | 0.74 | 0.90 |
| 14 | 41 | 23 | 55 | tr. | 15.61 | 6.5 | 15.61 | 3.75 | 4.16 | 6.2 | 296 | 169 | .... | 57 | 93 | 66 | 3.5 | N | 0.18 | 0.12 | 3.56 | 1.08 | 0.58 | .... |
| 15 | 37 | 20 | 53 | tr. | 18.65 | 5.4 | 18.65 | 4.60 | 4.05 | 5.2 | 328 | 136 | .... | 66 | 99 | 60 | 3.7 | P | 0.26 | 0.52 | 1.72 | 0.64 | 0.40 | 0.56 |
| 16 | 30 | 24 | 53 | 0.32 | 14.66 | 6.8 | 14.66 | 3.85 | 3.80 | 6.5 | 242 | 116 | .... | 63 | 93 | 56 | 3.7 | P | 0.30 | 0.70 | 1.28 | 0.44 | 0.32 | 0.60 |
| 17 | 27 | 22 | 52 | tr. | 12.28 | 15.6 | 12.28 | 2.95 | 4.54 | 7.8 | 158 | 90 | .... | 44 | 86 | 60 | 3.7 | P | 0.22 | 0.40 | 2.60 | 0.34 | 0.25 | 0.50 |
| 18 | 27 | 17 | 54 | tr. | 11.45 | 16.7 | 11.45 | 3.33 | 3.44 | 8.4 | 274 | 100 | .... | 34 | 99 | 61 | 3.6 | N | 0.16 | 0.49 | 3.90 | 0.52 | 0.37 | 0.30 |
| 19 | 33 | 21 | 54 | 0.00 | 7.10 | 27.0 | 7.10 | 2.50 | 3.58 | 13.5 | 202 | 84 | .... | 46 | 84 | 63 | 3.2 | P | 0.12 | 0.58 | ..... | ..... | ..... | ..... |
| 20 | 34 | 25 | 54 | 0.00 | 11.03 | 17.5 | 11.03 | 3.00 | 3.68 | 8.7 | 242 | 86 | .... | 37 | 92 | 63 | 2.4 | P | 0.14 | 0.86 | ..... | ..... | ..... | ..... |
| 21 | 54 | 33 | 53 | 0.00 | 11.80 | 16.3 | 11.80 | 3.44 | 3.43 | 8.1 | 596 | 112 | .... | 55 | 117 | 64 | 2.9 | P | 0.16 | 0.89 | ..... | ..... | ..... | ..... |
| 22 | 62 | 47 | 51 | 0.12 | 10.89 | 17.6 | 10.89 | 2.95 | 4.05 | 8.8 | 360 | 118 | .... | 71 | 88 | 65 | 3.0 | P | 0.25 | 1.05 | ..... | ..... | ..... | ..... |
| 23 | 62 | 53 | 56 | 0.28 | 14.19 | 13.5 | 14.19 | 4.06 | 3.49 | 6.7 | 710 | 132 | .... | 57 | 117 | 58 | 2.2 | P | 0.65 | 1.00 | 1.92 | 0.96 | 0.70 | 0.70 |
| 24 | 66 | 57 | 56 | 0.00 | 11.28 | 17.0 | 11.28 | 2.80 | 4.00 | 8.5 | 218 | 84 | .... | 61 | 56 | 46 | 3.0 | P | 0.50 | 1.15 | 2.64 | 0.48 | 0.62 | 0.70 |
| 25 | 50 | 39 | 55 | 0.00 | 11.45 | 17.0 | 11.45 | 2.80 | 4.10 | 8.4 | 378 | 80 | .... | 28 | 94 | 46 | 4.1 | P | 0.60 | 0.97 | 5.92 | 1.30 | 0.84 | 1.14 |
| 26 | 46 | 29 | 56 | 0.00 | 10.61 | 18.0 | 10.61 | 2.80 | 3.80 | 9.0 | 396 | 102 | .... | 38 | 90 | 72 | 4.2 | P | 0.21 | 1.30 | 2.36 | 0.80 | 0.88 | 1.40 |
| 27 | 44 | 30 | 56 | 0.00 | 10.06 | 19.0 | 10.06 | 2.80 | 3.60 | 9.5 | 166 | 88 | .... | 37 | 84 | 65 | 4.2 | P | 0.21 | 1.17 | 1.76 | 2.30 | 2.52 | 1.96 |
| 28 | 38 | 26 | 56 | 0.04 | 6.29 | 30.0 | 6.29 | 2.50 | 3.70 | .... | 180 | 68 | .... | 36 | 78 | 56 | 2.6 | ..... | 0.35 | 0.40 | ..... | ..... | ..... | ..... |
| 29 | 43 | 24 | 54 | 0.39 | 8.60 | 22.0 | 8.60 | 2.50 | 3.40 | .... | 518 | 109 | 74 | .... | 104 | 60 | 30 | 7.1 | P | 0.12 | 1.20 | 2.16 | 0.66 | 0.74 | .... |
| 30 | 29 | 14 | 54 | 0.21 | 9.97 | 19.0 | 9.97 | 2.80 | 3.60 | .... | 280 | 109 | 84 | .... | 91 | 50 | 30 | 8.7 | P | 0.25 | 0.85 | 1.72 | 0.22 | 0.24 | .... |
| 31 | 15 | 4 | 54 | tr. | 9.34 | 20.0 | 9.34 | 2.50 | 3.70 | .... | 109 | 80 | 84 | .... | 45 | 41 | 26 | 9.2 | N | 0.32 | 0.73 | 1.60 | 0.60 | 0.50 | .... |
| Avge. | 39 | 26 | 55 | .... | 11.80 | 13.0 | 11.80 | 3.10 | 3.90 | 8.0 | 340 | 105 | 81 | 50 | 100 | 60 | 30 | 4.6 | ..... | 0.20 | 0.65 | 2.70 | 0.90 | 0.80 | 0.80 |

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for February, 1909.

| Day of Month. | Temperature, Degrees, Fahr. | | | Rainfall, in inches. | Volume pumped, in millions of gallons per day. | Flow in septic tanks, average period, in hours. | Volume filtered, in millions of gallons per day. | Filter area in service during application of sewage, in acres. | Average rate of filtration during application of sewage, in millions of gallons per acre per day. | Flow in settling basin, average period, in hours. | Analytical Results, Parts per Million. | | | | | | | | | | Bacteria. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Air. | | | | | | | | | | Suspended Matter. | | | Oxygen Consumed. | | | Final Effluent. | | | | Millions per c. c. | | | |
| | Maximum. | Minimum. | Sewage. | | | | | | | | Screened sewage. | Septic effluent. | Settling basin effluent. | Screened sewage. | Septic effluent. | Settling basin effluent. | Dissolved oxygen. | Putrescibility (odor) incubated 24 hrs. @ 37° C. | Nitrites. | Nitrates. | Screened sewage. | Septic effluent. | Filter effluent. | Settling basin effluent. |
| 1 | 23 | 0 | 52 | 0.00 | 10.2 | 19 | 10.2 | 2.7 | 3.8 | .... | 172 | 70 | 50 | 74 | 39 | 22 | 9.6 | N | 0.15 | 0.92 | 3.00 | 0.50 | 0.50 | ..... |
| 2 | 40 | 17 | 53 | 0.00 | 10.5 | 18 | 10.5 | 2.5 | 4.2 | .... | 176 | 85 | 71 | 74 | 48 | 28 | 7.3 | N | 0.35 | 0.92 | 1.80 | 0.80 | 0.70 | ..... |
| 3 | 44 | 30 | 53 | 0.00 | 11.0 | 17 | 11.0 | 3.6 | 3.1 | 4.5 | 210 | 114 | 59 | 74 | 52 | 29 | 6.2 | P | 0.22 | 0.88 | 1.60 | 0.75 | 0.75 | 0.90 |
| 4 | 56 | 34 | 52 | 0.00 | 12.2 | 16 | 12.2 | 3.4 | 3.6 | 4.0 | 214 | 114 | 59 | 67 | 54 | 27 | 5.2 | P | 0.45 | 0.10 | 2.75 | 0.55 | 0.60 | 0.80 |
| 5 | 56 | 41 | 53 | 0.31 | 13.7 | 14 | 13.7 | 3.3 | 4.2 | 3.5 | 320 | 89 | 76 | 72 | 62 | 27 | ..... | P | 0.05 | 0.45 | ..... | ..... | ..... | ..... |
| 6 | 41 | 34 | 53 | 0.08 | 12.2 | 16 | 12.2 | 3.3 | 3.7 | 4.0 | 522 | 142 | 74 | 100 | 47 | 23 | 7.2 | P | 0.50 | 0.65 | 0.80 | 0.40 | 0.45 | 0.40 |
| 7 | 40 | 30 | 52 | 0.00 | 14.1 | 13 | 14.1 | 3.0 | 4.7 | 7.0 | 134 | 103 | 51 | 37 | 38 | 20 | 6.6 | P | 0.75 | 0.90 | 1.40 | 0.46 | 0.43 | 0.55 |
| 8 | 43 | 28 | 55 | 0.00 | 17.4 | 11 | 17.4 | 4.5 | 3.85 | 5.5 | 191 | 106 | 32 | 71 | 46 | 19 | 8.1 | N | 0.60 | 1.19 | 1.60 | 0.48 | 0.40 | 0.24 |
| 9 | 48 | 36 | 53 | 0.40 | 21.4 | 9 | 21.4 | 5.6 | 3.85 | 4.5 | 451 | 164 | 81 | 83 | 47 | 26 | 6.6 | P | 0.32 | 0.73 | 1.20 | 0.70 | 0.44 | 0.38 |
| 10 | 48 | 21 | 51 | tr. | 20.0 | 9 | 20.0 | 6.2 | 3.25 | 5.0 | 275 | 155 | 77 | 72 | 46 | 24 | 9.4 | PN | 0.70 | 2.74 | 0.88 | 0.42 | 0.16 | 0.28 |
| 11 | 36 | 30 | 52 | 0.00 | 12.6 | 15 | 12.6 | 3.1 | 4.05 | 7.5 | 182 | 94 | 54 | 53 | 34 | 24 | 8.4 | PN | 0.67 | 1.53 | 0.40 | 0.62 | 0.28 | 0.34 |
| 12 | 48 | 29 | 54 | 0.54 | 13.7 | 14 | 13.7 | 3.2 | 4.25 | 7.0 | 179 | 86 | 57 | 61 | 37 | 25 | 7.3 | P | 0.68 | 0.42 | 1.30 | 0.50 | 0.35 | 0.30 |
| 13 | 52 | 41 | 52 | 0.01 | 16.5 | 12 | 16.5 | 4.0 | 4.10 | 6.0 | 359 | 150 | 63 | 78 | 42 | 21 | 6.5 | P | 0.50 | 1.02 | 0.95 | 0.25 | 0.20 | 0.30 |
| 14 | 60 | 37 | 51 | 0.56 | 18.7 | 10 | 18.7 | 5.0 | 3.75 | .... | 580 | 116 | 72 | 70 | 34 | 22 | 9.3 | N | 0.86 | 2.16 | 1.20 | 0.40 | 0.30 | ..... |
| 15 | 38 | 27 | 49 | 0.42 | 17.8 | 11 | 5.2 | 4.6 | ..... | .... | 460 | 118 | 75 | 68 | 32 | 18 | 10.6 | N | 0.70 | 4.47 | 1.30 | 0.30 | 0.20 | ..... |
| 16 | 28 | 20 | 48 | 0.24 | 18.4 | ..... | ..... | ..... | ..... | .... | 278 | 132 | .... | 47 | 49 | .... | ..... | ..... | ..... | ..... | 0.60 | 0.10 | ..... | ..... |
| 17 | 32 | 17 | 49 | 0.00 | 18.5 | 10 | 9.12 | 4.4 | 4.15 | .... | 174 | 120 | .... | 55 | 42 | .... | ..... | P | ..... | ..... | 1.20 | 0.40 | 0.30 | ..... |
| 18 | 50 | 29 | 49 | 0.00 | 18.8 | 10 | 18.8 | 5.0 | 3.70 | .... | 212 | 98 | 52 | 53 | 34 | 22 | 10.2 | N | 0.76 | 5.39 | 1.45 | 0.50 | 0.25 | ..... |
| 19 | 52 | 38 | 49 | 0.21 | 19.0 | 10 | 19.0 | 5.0 | 3.80 | .... | 264 | 100 | 80 | 47 | 28 | 20 | 9.7 | N | 0.70 | 7.20 | 0.75 | 0.30 | 0.30 | ..... |
| 20 | 44 | 33 | 45 | 0.00 | 19.6 | 10 | 6.24 | 5.0 | 3.75 | .... | 190 | 120 | 52 | 24 | 26 | 17 | ..... | N | 0.76 | 6.84 | 0.15 | 0.20 | ..... | ..... |
| 21 | 49 | 32 | 44 | tr. | 20.9 | ..... | ..... | ..... | ..... | .... | 170 | 102 | .... | 14 | 17 | .... | ..... | ..... | ..... | ..... | 0.06 | 0.18 | ..... | ..... |
| 22 | 55 | 29 | 44 | 0.00 | 21.2 | ..... | ..... | ..... | ..... | .... | 110 | 104 | .... | 13 | 15 | .... | ..... | ..... | ..... | ..... | 0.03 | 0.05 | ..... | ..... |
| 23 | 64 | 42 | 46 | 2.05 | 15.8 | ..... | ..... | ..... | ..... | .... | 814 | 174 | .... | 72 | 30 | .... | ..... | ..... | ..... | ..... | 0.50 | 0.25 | ..... | ..... |
| 24 | 61 | 35 | 51 | 0.14 | 8.9 | ..... | ..... | ..... | ..... | .... | 724 | 230 | .... | 58 | 27 | .... | ..... | ..... | ..... | ..... | 0.25 | 0.10 | ..... | ..... |
| 25 | 35 | 19 | 49 | tr. | 10.4 | ..... | ..... | ..... | ..... | .... | 292 | 186 | .... | 18 | 18 | .... | ..... | ..... | ..... | ..... | 0.20 | 0.20 | ..... | ..... |
| 26 | 46 | 22 | 48 | 0.00 | 10.5 | ..... | ..... | ..... | ..... | .... | 200 | 142 | .... | 17 | 16 | .... | ..... | ..... | ..... | ..... | 0.12 | 0.07 | ..... | ..... |
| 27 | 51 | 31 | 49 | tr. | 10.8 | ..... | ..... | ..... | ..... | .... | 84 | 100 | .... | 8 | 13 | .... | ..... | ..... | ..... | ..... | 0.08 | 0.05 | ..... | ..... |
| 28 | 39 | 30 | 50 | 0.01 | 9.7 | ..... | ..... | ..... | ..... | .... | 58 | 104 | .... | 7 | 14 | .... | ..... | ..... | ..... | ..... | 0.06 | 0.10 | ..... | ..... |
| Avge. | 46 | 29 | 50 | .... | 15.2 | 12 | 13.8 | 4.1 | 3.90 | 5.0 | 285 | 120 | 65 | 53 | 35 | 23 | 8.0 | ..... | 0.54 | 2.14 | 0.95 | 0.35 | 0.35 | 0.45 |

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for March, 1909.

| Day of Month. | Temperature, Degrees, Fahr. | | | Rainfall, in inches. | Flow in septic tanks, av. period, in hours. | Volume filtered, in mill. of gal. per day. | Filter area in service during application of sewage, in acres. | Av. rate of filtration during application of sewage, in millions of gallons per acre per day. | Flow in settling basin, av. period, in hrs. | Analytical Results, Parts per Million. | | | | | | | | | | | Bacteria. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Suspended Matter. | | | | Oxygen Consumed. | | | | Final Effluent. | | | | | Millions per c. c. | | | |
| | Air. | | Sewage. | | | | | | | Screened sewage. | Septic effluent. | Filter effluent. | Settling basin effluent. | Screened sewage. | Septic effluent. | Filter effluent. | Settling basin effluent. | Dissolved oxygen. | Putrescibility (odor) incubated 24 hrs. @ 37° C. | Nitrites. | Nitrates. | Screened sewage. | Septic effluent. | Filter effluent. | Settling basin effluent. |
| | Max. | Min. | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 57 | 28 | 53 | 0.35 | 16 | 5.50 | 2.50 | 3.77 | .... | 84 | 68 | 38 | .... | 26 | 13 | 9 | .... | 10.7 | N | 0.60 | 11.34 | 0.50 | 0.04 | 0.04 | .... |
| 2 | 54 | 39 | 53 | 0.14 | 14 | 14.23 | 3.23 | 4.43 | .... | 89 | 83 | 59 | .... | 25 | 21 | 14 | .... | 11.3 | N | 1.18 | 8.86 | 0.41 | 0.38 | 0.42 | .... |
| 3 | 58 | 39 | 53 | 0.22 | 11 | 16.69 | 3.75 | 4.45 | .... | 130 | 84 | 73 | .... | 41 | 29 | 17 | .... | 11.7 | N | 1.10 | 6.25 | 0.65 | 0.48 | 0.35 | .... |
| 4 | 40 | 24 | 53 | 0.00 | 11 | 17.49 | 4.06 | 4.32 | .... | 92 | 80 | 59 | .... | 41 | 29 | 18 | .... | 11.2 | NP | 1.20 | 6.50 | 0.72 | 0.36 | 0.33 | .... |
| 5 | 40 | 22 | 53 | 0.00 | 11 | 16.80 | 4.06 | 4.11 | .... | 132 | 72 | 57 | .... | 38 | 30 | 23 | .... | 11.2 | NP | 1.20 | 5.12 | 0.54 | 0.40 | 0.42 | .... |
| 6 | 47 | 38 | 53 | 0.01 | 13 | 15.03 | 3.75 | 4.00 | .... | 118 | 84 | 54 | .... | 48 | 31 | 22 | .... | 10.5 | N | 0.90 | 5.70 | 0.70 | 0.34 | 0.43 | .... |
| 7 | ..... | .... | 51 | 0.00 | .... | 15.53 | 3.75 | 4.14 | .... | 130 | 76 | 40 | .... | 27 | 28 | 19 | .... | 10.3 | N | 0.90 | 4.85 | 1.10 | 0.38 | 0.21 | .... |
| 8 | 55 | 34 | 54 | 0.03 | .... | 18.20 | 4.06 | 4.15 | .... | 236 | 96 | 58 | .... | 48 | 30 | 15 | .... | 10.5 | P | 1.18 | 6.48 | 1.35 | 0.62 | 0.36 | .... |
| 9 | 59 | 42 | 51 | 0.98 | .... | 9.70 | 4.50 | 2.60 | .... | 378 | 142 | 72 | .... | 48 | 30 | 20 | .... | 9.2 | P | 1.06 | 6.20 | 0.42 | 0.38 | 0.30 | .... |
| 10 | 56 | 38 | 51 | tr. | .... | ..... | ..... | ..... | .... | 186 | 122 | .... | .... | 21 | 22 | .... | .... | ..... | ..... | ..... | ..... | 0.24 | 0.18 | .... | .... |
| 11 | 42 | 32 | 51 | 0.00 | .... | 4.35 | 2.50 | 3.48 | .... | 286 | 86 | 46 | .... | 26 | 14 | 11 | .... | 10.4 | N | 0.42 | 7.48 | 0.15 | 0.16 | 0.03 | .... |
| 12 | 50 | 30 | 51 | tr. | .... | 11.05 | 2.50 | 4.42 | .... | 106 | 82 | 49 | .... | 11 | 12 | 10 | .... | 10.7 | N | 0.46 | 6.14 | ..... | 0.12 | .... | .... |
| 13 | 48 | 39 | 52 | 0.00 | .... | 17.34 | 4.17 | 4.16 | .... | 172 | 82 | 46 | .... | 28 | 15 | 11 | .... | 10.2 | NP | 0.84 | 5.16 | 0.36 | 0.10 | 0.09 | .... |
| 14 | 53 | 27 | 51 | tr. | 11 | 18.07 | 4.63 | 3.90 | .... | 68 | 62 | 27 | .... | 18 | 16 | 11 | .... | 11.2 | N | 0.60 | 5.70 | 0.28 | 0.10 | 0.10 | .... |
| 15 | 44 | 30 | 53 | 0.00 | 9.5 | 20.11 | 4.58 | 4.39 | .... | 126 | 60 | 26 | .... | 41 | 23 | 12 | .... | 10.8 | N | 0.82 | 4.02 | 1.35 | 0.41 | 0.21 | .... |
| 16 | 41 | 29 | 54 | 0.03 | 9.5 | 20.08 | 4.69 | 4.28 | .... | 128 | 84 | 41 | .... | 44 | 31 | 16 | .... | 10.1 | N | 1.10 | 6.70 | 1.47 | 0.64 | 0.32 | .... |
| 17 | 33 | 19 | 53 | 0.00 | 10 | 18.39 | 4.32 | 4.22 | .... | 170 | 78 | 48 | .... | 45 | 30 | 22 | .... | 10.5 | N | 1.10 | 3.20 | 1.57 | 0.74 | 0.52 | .... |
| 18 | 46 | 22 | 54 | 0.01 | 10 | 19.19 | 3.75 | 5.14 | .... | 176 | 80 | 48 | .... | 48 | 28 | 22 | .... | 9.4 | P | 1.04 | 1.16 | 1.60 | 0.75 | 0.65 | .... |
| 19 | 54 | 41 | 54 | 0.07 | 10 | 19.03 | 3.75 | 5.07 | .... | 334 | 78 | 59 | .... | 63 | 32 | 27 | .... | 9.0 | P | 0.84 | 0.76 | 1.26 | 0.96 | 0.69 | .... |
| 20 | 55 | 35 | 55 | 0.00 | 11 | 18.00 | 3.75 | 4.80 | .... | 288 | 80 | 52 | .... | 65 | 28 | 22 | .... | 9.5 | P | 0.96 | 1.04 | 2.92 | 1.06 | 0.94 | .... |
| 21 | 57 | 27 | 54 | 0.00 | 11 | 17.12 | 3.98 | 4.30 | .... | 160 | 70 | 39 | .... | 40 | 27 | 20 | .... | 9.2 | N | 0.94 | 1.96 | 1.28 | 1.02 | 0.68 | .... |
| 22 | 53 | 25 | 53 | 0.00 | 11 | 17.21 | 4.90 | 3.50 | .... | 134 | 156 | 38 | .... | 48 | 43 | 16 | .... | 9.6 | P | 0.72 | 1.38 | 2.28 | 0.60 | 0.32 | .... |
| 23 | 50 | .... | 55 | 0.00 | 10 | 18.40 | 3.75 | 4.90 | 2.6 | 164 | 78 | 46 | 45 | 56 | 40 | 28 | 21 | 7.1 | PN | 0.44 | 1.26 | 1.76 | 0.71 | 0.53 | 0.50 |
| 24 | 62 | 32 | 55 | 0.65 | 11 | 17.37 | 4.06 | 4.20 | 2.7 | 350 | 106 | 49 | 44 | 74 | 38 | 20 | 21 | 6.2 | P | 0.29 | 0.91 | 2.44 | 1.52 | 1.07 | 0.89 |
| 25 | 57 | 33 | 52 | 0.18 | 11 | 17.96 | 4.58 | 3.90 | 2.7 | 260 | 152 | 82 | 67 | 61 | 37 | 20 | 18 | 8.0 | P | 0.42 | 2.78 | 0.78 | 0.54 | .... | 0.66 |
| 26 | 50 | 30 | 53 | 0.00 | 10 | 18.00 | 4.17 | 4.30 | 2.7 | 110 | 79 | 43 | 41 | 40 | 34 | 15 | 14 | 9.2 | PN | 0.58 | 3.62 | 0.64 | 0.45 | 0.40 | 0.22 |
| 27 | 54 | 36 | 54 | 0.00 | 11 | 17.87 | 4.37 | 4.00 | 2.7 | 160 | 76 | 41 | 34 | 44 | 30 | 16 | 14 | 8.9 | P | 0.62 | 2.78 | 2.14 | 0.68 | 0.40 | 0.40 |
| 28 | 50 | 37 | 52 | 0.00 | 10 | 18.49 | 4.70 | 3.90 | 2.6 | 178 | 76 | 28 | 28 | 40 | 25 | 12 | 12 | 9.4 | N | 0.80 | 2.20 | 1.52 | 0.49 | 0.33 | 0.24 |
| 29 | 50 | 29 | 54 | tr. | 10 | 18.42 | 4.70 | 3.90 | 2.6 | 230 | 74 | 33 | 27 | 71 | 26 | 14 | 12 | 10.2 | N | 0.80 | 2.90 | 2.14 | 0.58 | 0.45 | 0.25 |
| 30 | 46 | 32 | 54 | 0.01 | 14 | 13.96 | 3.75 | 3.70 | 3.4 | 126 | 82 | 40 | 35 | 57 | 32 | 15 | 16 | 7.6 | P | 0.58 | 2.12 | 1.06 | 1.03 | 0.88 | 0.89 |
| 31 | 46 | 34 | 54 | 0.00 | 14 | 13.41 | 4.06 | 3.30 | 3.6 | 220 | 84 | 42 | 31 | 53 | 33 | 19 | 17 | 7.9 | N | 0.22 | 1.28 | 1.94 | 0.75 | 0.43 | 0.45 |
| Avge. | 50 | 32 | 53 | .... | 11.6 | 16.10 | 3.98 | 4.12 | 2.8 | 178 | 87 | 47 | 39 | 43 | 28 | 17 | 16 | 9.7 | ..... | 0.80 | 4.20 | 1.18 | 0.55 | 0.43 | 0.50 |

NOTE.—All primary and secondary tanks in service continuously. Filters operated continuously for 6 hours, then rested for 6 hours, more or less, the length of the resting period being governed by the volume of sewage. The 6-hour period in service was split up as follows: First 2 hours, 3.0 ft. head on nozzles; second 2 hours, 6.0 ft. head on nozzles; third 2 hours, 9.0 ft. head on nozzles. Settling basins cleaned during first 3 weeks of the month.

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for April, 1909.

| Day of Month. | Temperature, Degrees, Fahr. | | | Rainfall, in inches. | Volume pumped, in millions of gallons per day. | Flow in septic tanks, av. period, in hours. | Volume filtered, in mill. of gal. per day. | Filter area in service during application of sewage, in acres. | Av. rate of filtration during application of sewage, in millions of gallons per acre per day. | Flow in settling bas. in, av. period, in hrs. | Analytical Results, Parts per Million. | | | | | | | | | | Bacteria. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Susp'd Matter. | | | | Oxygen Cons'd. | | | Final Effluent. | | | Millions per c. c. | | | |
| | Air. | | Sewage. | | | | | | | | Screened sewage. | Septic effluent. | Filter effluent. | Settling bas. in effluent. | Screened sewage. | Septic effluent. | Filter effluent. | Settling bas. in effluent. | Dissolved oxygen. | Putrescibility (odor) incubated 24 hrs. @ 37° C. | Nitrites. | Nitrates. | Screened sewage. | Septic effluent. | Filter effluent. | Settling bas. in effluent. |
| | Max. | Min. | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 46 | 36 | 56 | 0.00 | 11.78 | 16 | 12.20 | 3.12 | 3.91 | 4 | 150 | 100 | 38 | 39 | 58 | 33 | 17 | 16 | 6.6 | N | 0.38 | 1.12 | 1.54 | 0.54 | 0.33 | 0.51 |
| 2 | 53 | 36 | 55 | 0.06 | 10.48 | 18 | 10.26 | 2.50 | 4.10 | 5 | 224 | 84 | 36 | 27 | 68 | 36 | 16 | 16 | 6.6 | PN | 0.26 | 1.14 | 1.10 | 0.59 | 0.39 | 0.59 |
| 3 | 54 | 34 | 55 | 0.01 | 8.17 | 23 | 9.02 | 2.50 | 3.61 | 5 | 108 | 90 | 40 | 31 | 40 | 35 | 16 | 16 | 6.2 | N | 0.25 | 0.75 | 1.60 | 1.10 | 0.75 | 0.37 |
| 4 | ..... | ..... | 55 | 0.00 | 5.39 | 36 | 6.99 | 2.50 | 2.40 | 7 | 54 | 84 | 38 | 35 | 20 | 30 | 18 | 16 | 6.0 | P | 0.20 | 1.10 | 0.70 | 0.30 | 0.20 | 0.45 |
| 5 | 74 | 34 | 55 | 0.00 | 6.95 | 27 | 4.20 | 2.35 | 2.40 | 8 | 68 | 56 | 22 | 18 | 48 | 26 | 13 | 13 | 4.9 | P | 0.23 | 0.67 | 1.26 | 0.13 | ..... | ..... |
| 6 | 78 | 57 | 55 | 1.00 | 11.55 | 16.5 | 8.00 | 2.70 | 4.00 | 6 | 434 | 76 | 64 | 36 | 63 | 27 | 15 | 13 | 5.7 | N | 0.28 | 2.52 | 5.00 | 0.72 | 0.37 | 0.48 |
| 7 | 66 | 46 | 55 | 0.00 | 15.54 | 12 | ..... | ..... | ..... | .... | 520 | 122 | .... | .... | 48 | 20 | .... | .... | ..... | ..... | ..... | ..... | 0.20 | 0.11 | ..... | ..... |
| 8 | 54 | 34 | 52 | tr. | 13.26 | 14.5 | ..... | ..... | ..... | .... | 116 | 90 | .... | .... | 27 | 18 | .... | .... | ..... | ..... | ..... | ..... | 0.16 | 0.14 | ..... | ..... |
| 9 | 50 | 29 | 51 | 0.04 | 11.23 | 17 | ..... | ..... | ..... | .... | 154 | 97 | .... | .... | 20 | 16 | .... | .... | ..... | ..... | ..... | ..... | 0.20 | 0.38 | ..... | ..... |
| 10 | 41 | 23 | 52 | tr. | 11.61 | 16.5 | 6.23 | 2.80 | 4.45 | .... | 128 | 88 | 63 | .... | 38 | 18 | 17 | .... | 11.5 | N | 0.80 | 7.00 | 0.61 | 0.04 | 0.28 | .... |
| 11 | 52 | 26 | 52 | 0.00 | 10.89 | 17.5 | 11.13 | 2.97 | 3.75 | 4.4 | 54 | 50 | 58 | .... | 14 | 18 | 14 | .... | 11.2 | N | 1.15 | 4.40 | 0.36 | 0.34 | 0.13 | 0.12 |
| 12 | 66 | 45 | 53 | 0.00 | 10.04 | 19 | 10.04 | 2.92 | 3.44 | 4.8 | 80 | 46 | 42 | 20 | 36 | 14 | 10 | 8 | 10.5 | N | 1.10 | 3.40 | 0.57 | 0.27 | 0.11 | 0.11 |
| 13 | 72 | 54 | 54 | 0.16 | 9.94 | 20 | 9.07 | 2.81 | 3.22 | 5.2 | 86 | 62 | 49 | .... | 21 | 18 | 13 | 12 | 7.5 | N | 0.75 | 2.75 | 0.45 | 0.89 | 0.65 | 0.46 |
| 14 | 57 | 35 | 54 | 0.00 | 9.15 | 21 | 9.32 | 2.50 | 3.73 | 5.1 | 80 | 42 | 41 | 21 | 35 | 21 | 13 | .... | 7.8 | P | 0.46 | 1.40 | 0.57 | 0.98 | 0.88 | 0.46 |
| 15 | 63 | 32 | 55 | 0.00 | 8.89 | 21.5 | 8.38 | 2.29 | 3.66 | 5.7 | 106 | 44 | 39 | 13 | 97 | 25 | 22 | 14 | 7.7 | PN | 0.44 | 2.30 | 2.89 | 1.31 | 0.66 | 0.88 |
| 16 | 73 | 44 | 55 | 0.00 | 8.61 | 22.5 | 8.44 | 2.13 | 3.96 | 5.7 | 60 | 54 | 48 | 21 | 32 | 29 | 17 | 16 | 5.8 | PN | 0.52 | 2.50 | 0.96 | 0.86 | 0.73 | 0.65 |
| 17 | 77 | 56 | 55 | tr. | 8.55 | 22.5 | 9.23 | 2.50 | 3.70 | 5.2 | 106 | 52 | 40 | 9 | 26 | 23 | 15 | 14 | 6.3 | PN | 0.52 | 1.00 | 1.48 | 1.20 | 0.50 | 0.53 |
| 18 | 81 | 59 | 55 | 0.00 | 7.88 | 22 | 8.79 | 2.50 | 3.50 | 5.5 | 58 | 46 | 63 | 12 | 16 | 17 | 14 | 10 | 5.7 | N | 0.46 | 2.90 | 0.72 | 0.64 | 2.75 | 0.36 |
| 19 | 84 | 59 | 57 | 0.03 | 13.20 | 12 | 12.28 | 3.38 | 3.63 | 4.0 | 202 | 140 | 61 | 22 | 58 | 26 | 12 | 9 | 7.8 | N | 0.68 | 2.40 | 3.00 | 0.24 | 5.30 | 0.20 |
| 20 | 70 | 43 | 56 | 0.25 | 15.99 | 12 | 16.26 | 4.22 | 3.85 | 3.0 | 604 | 108 | 60 | 30 | 99 | 29 | 16 | 17 | 6.5 | PN | 0.58 | 2.00 | 3.64 | 0.58 | 0.80 | 0.65 |
| 21 | 72 | 46 | 57 | 0.48 | 15.81 | 11 | 15.74 | 4.48 | 3.51 | 6.0 | 410 | 84 | 75 | 48 | 96 | 30 | 17 | 15 | 4.2 | PN | 0.54 | 1.20 | 3.65 | 1.44 | 0.97 | 0.93 |
| 22 | 72 | 45 | 59 | 0.00 | 15.24 | 12.5 | 14.96 | 3.75 | 3.99 | 6.5 | 198 | 76 | 52 | 29 | 66 | 26 | 16 | 13 | 5.2 | N | 0.67 | 0.80 | 1.88 | 1.08 | 0.95 | 1.94 |
| 23 | 56 | 44 | 59 | 0.00 | 16.28 | 12 | 16.85 | 3.80 | 4.43 | 5.5 | 422 | 86 | 69 | 31 | 58 | 30 | 18 | 15 | 3.5 | P | 0.62 | 1.10 | 1.20 | 0.90 | 1.60 | .... |
| 24 | 58 | 39 | 59 | 0.00 | 15.40 | 12.5 | 15.46 | 3.85 | 4.01 | 6.0 | 218 | 62 | 47 | 26 | 66 | 26 | 14 | 13 | 4.9 | PN | 0.62 | 1.70 | 1.76 | 0.80 | 0.48 | 0.81 |
| 25 | 70 | 38 | 58 | 0.34 | 14.24 | 13 | 13.41 | 3.23 | 4.15 | 7.0 | 122 | 66 | 64 | 10 | 34 | 26 | 16 | 10 | 4.8 | PN | 0.60 | 1.80 | 1.44 | 0.96 | 0.52 | 0.83 |
| 26 | 70 | 35 | 60 | 0.00 | 14.64 | 12.5 | 14.78 | 3.75 | 3.94 | 6.5 | 252 | 58 | 65 | 27 | 69 | 24 | 16 | 13 | 8.1 | N | 0.75 | 2.25 | 2.40 | 0.88 | 0.72 | 0.75 |
| 27 | 70 | 42 | 59 | 0.05 | 15.62 | 12 | 15.48 | 3.54 | 4.37 | 6.0 | 196 | 90 | 86 | 32 | 66 | 35 | 19 | 16 | 2.7 | PN | 0.68 | 1.80 | 2.24 | 1.20 | 0.76 | 1.31 |
| 28 | 70 | 34 | 59 | tr. | 15.13 | 12.5 | 15.00 | 3.59 | 4.18 | 6.5 | 288 | 74 | 113 | 28 | 72 | 31 | 21 | 16 | 0.6 | P | 0.58 | 1.80 | 1.94 | 1.42 | 0.82 | 1.28 |
| 29 | 81 | 45 | 60 | tr. | 14.79 | 12 | 14.93 | 3.59 | 4.16 | 6.5 | 116 | 94 | 100 | 30 | 58 | 35 | 25 | 15 | 3.9 | PN | 0.64 | 1.90 | 2.10 | 1.06 | 0.98 | 1.17 |
| 30 | 83 | 58 | 61 | 0.78 | 17.68 | 10.5 | 13.32 | 4.27 | 4.40 | 7.0 | 596 | 136 | 116 | 22 | 76 | 36 | 23 | 18 | 4.0 | P | 0.64 | 2.30 | 1.46 | 1.10 | 0.67 | 1.13 |
| Avge. | 66 | 41 | 56 | .... | 12.13 | 16.9 | 11.47 | 3.13 | 3.80 | 5.66 | 209 | 78 | 59 | 26 | 57 | 26 | 16 | 14 | 6.2 | ..... | 0.57 | 2.08 | 1.57 | 0.74 | 0.90 | 0.71 |

NOTE.—All primary and secondary tanks in service continuously. Operation of filters to April 22d, same as in March. April 22d, method of operation changed as follows: Period of service reduced to 2 hours, and the length of the resting period determined by the volume of sewage pumped. A single head used on the nozzles throughout the period in service with the following heads alternating in order as follows: First period in service, 4.0 ft. head. Second period in service, 7.0 ft. head. Third period in service, 9.0 ft. head. Fourth period in service, 4.0 ft. head. Fifth period in service, 7.0 ft. head. Sixth period in service, 9.0 ft. head, etc.

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for May, 1909.

| Day of Month. | Temperature, Degrees, Fahr. | | | Rainfall, in inches. | Volume pumped, in millions of gallons per day. | Flow in septic tanks, average period, in hours. | Volume filtered, in millions of gallons per day. | Filter area in service during application of sewage, in acres. | Average rate of filtration during application of sewage, in millions of gallons per acre per day. | Flow in settling basin, average period, in hours. | Analytical Results, Parts Per Million. | | | | | | | | | | | | Bacteria. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Air. | | Sewage. | | | | | | | | Suspended Matter. | | | | Oxygen Consumed. | | | | Final Effluent. | | | | | | Millions per c. c. | | | |
| | Maximum. | Minimum. | | | | | | | | | Screened sewage. | Septic effluent. | Filter effluent. | Settling basin effluent. | Screened sewage. | Septic effluent. | Filter effluent. | Settling basin effluent. | Chlorine. | Dissolved oxygen. | Putrescibility (odor) incubated 24 hrs. @ 37° C. | Nitrites. | Nitrates. | Screened sewage. | Septic effluent. | Filter effluent. | Settling basin effluent. |
| 1 | 70 | 39 | 57 | tr. | 17.60 | 10 | ..... | ..... | ..... | .... | 406 | 180 | .... | .... | 28 | 23 | .... | .... | 17 | .... | ..... | ..... | ..... | 0.60 | 0.10 | ..... | .... |
| 2 | 51 | 34 | 54 | tr. | 13.75 | 13 | ..... | ..... | ..... | .... | 410 | 300 | .... | .... | 22 | 23 | .... | .... | 20 | .... | ..... | ..... | ..... | 0.52 | ..... | ..... | .... |
| 3 | 53 | 35 | 53 | 0.36 | 11.79 | 15 | ..... | ..... | ..... | .... | 254 | 170 | .... | .... | 22 | 17 | .... | .... | 18 | .... | ..... | ..... | ..... | ..... | ..... | ..... | .... |
| 4 | 54 | 35 | 56 | 0.50 | 10.40 | 16 | ..... | ..... | ..... | .... | 218 | 76 | .... | .... | 35 | 21 | .... | .... | 38 | .... | ..... | ..... | ..... | 1.92 | 0.97 | ..... | .... |
| 5 | ..... | ..... | 53 | 0.17 | 9.01 | 19 | 4.11 | 2.50 | 3.30 | .... | 132 | 128 | 364 | .... | 19 | 27 | 45 | .... | 24 | .... | ..... | 0.68 | 7.10 | 0.25 | 0.59 | 0.70 | .... |
| 6 | 78 | 56 | 57 | 0.00 | 12.82 | 14 | 12.34 | 3.12 | 4.00 | .... | 144 | 58 | 740 | .... | 38 | 15 | 40 | .... | 52 | .... | ..... | 0.74 | 5.30 | 1.42 | 0.60 | ..... | .... |
| 7 | 84 | 52 | 59 | 0.01 | 14.26 | 12.5 | 14.60 | 3.65 | 4.00 | .... | 300 | 60 | 164 | .... | 45 | 24 | 26 | .... | 80 | 9.2 | PN | 0.78 | 2.60 | 4.60 | 1.10 | 0.80 | .... |
| 8 | 74 | 42 | 59 | 0.00 | 12.63 | 14.5 | 12.70 | 3.12 | 4.07 | 4 | 180 | 218 | 138 | 33 | 30 | 29 | 21 | 14 | 58 | 5.5 | N | 0.49 | 1.90 | 1.92 | 6.45 | 2.55 | 1.44 |
| 9 | 81 | 61 | 58 | 0.52 | 13.47 | 13.4 | 13.61 | 3.44 | 3.95 | 3.5 | 272 | 66 | 136 | 32 | 47 | 22 | 20 | 13 | 68 | 5.8 | N | 0.52 | 2.5 | 1.17 | 1.52 | 1.03 | 1.21 |
| 10 | 81 | 47 | 59 | 0.94 | 15.85 | .... | 1.76 | 0.42 | 4.20 | 3.4 | 566 | 72 | .... | .... | 44 | 17 | .... | .... | 21 | .... | ..... | ..... | ..... | 6.80 | 3.06 | ..... | .... |
| 11 | 61 | 40 | 55 | 0.00 | 18.15 | .... | ..... | ..... | ..... | .... | 274 | 202 | .... | .... | 18 | 19 | .... | .... | 15 | .... | ..... | ..... | ..... | ..... | 0.26 | ..... | .... |
| 12 | 70 | 40 | 56 | 0.00 | 17.01 | .... | ..... | ..... | ..... | .... | 112 | 118 | .... | .... | 14 | 16 | .... | .... | 17 | .... | ..... | ..... | ..... | 0.85 | 0.26 | ..... | .... |
| 13 | 74 | 48 | 56 | tr. | 16.42 | .... | ..... | ..... | ..... | .... | 50 | 60 | .... | .... | 10 | 10 | .... | .... | 20 | .... | ..... | ..... | ..... | ..... | 0.12 | ..... | .... |
| 14 | 77 | 58 | 57 | 0.00 | 11.10 | 15.7 | 3.11 | 1.87 | 3.32 | .... | 42 | 44 | 185 | .... | 8 | 7 | 22 | .... | 26 | 9.7 | N | 0.65 | 8.1 | 0.23 | 0.29 | 0.18 | .... |
| 15 | 88 | 59 | 55 | 0.23 | 7.35 | 24 | 6.79 | 1.77 | 3.80 | .... | 52 | 15 | 156 | .... | 11 | 7 | 16 | .... | 29 | 10.1 | N | 0.81 | 6.6 | 1.17 | ..... | 0.31 | .... |
| 16 | 80 | 56 | 55 | 0.00 | 6.37 | 38 | 6.79 | 1.87 | 3.63 | .... | 13 | 32 | 57 | .... | 9 | 8 | 10 | .... | 24 | 10.1 | N | 1.20 | 4.80 | ..... | 0.15 | ..... | .... |
| 17 | 78 | 47 | 57 | 0.00 | 10.32 | 17 | 10.32 | 2.55 | 4.05 | .... | 122 | 12 | 54 | .... | 37 | 11 | 13 | .... | 218 | 10.2 | N | 1.02 | 4.20 | 3.90 | 2.95 | 0.42 | .... |
| 18 | 75 | 47 | 61 | 0.00 | 15.81 | 11.7 | 15.53 | 3.60 | 4.30 | .... | 202 | 38 | 82 | .... | 53 | 21 | 17 | .... | 66 | 8.5 | N | 0.45 | 1.65 | 3.52 | 2.21 | 1.16 | .... |
| 19 | 78 | 48 | 61 | 0.00 | 15.13 | 12 | 15.90 | 3.75 | 4.24 | 3.2 | 204 | 54 | 85 | 25 | 58 | 30 | 18 | 13 | 57 | 7.7 | P | 0.66 | 1.30 | 2.27 | 1.77 | 1.07 | 1.22 |
| 20 | 77 | 52 | 60 | 0.99 | 16.01 | 11.4 | 15.34 | 3.64 | 4.21 | 3.0 | 278 | 46 | 33 | 15 | 64 | 20 | 14 | 14 | 57 | 5.2 | P | 0.42 | 1.50 | 2.10 | 1.13 | 0.56 | 0.73 |
| 21 | 67 | 54 | 59 | 0.11 | 17.88 | 10.5 | 17.32 | 3.85 | 4.50 | .... | 112 | 46 | 33 | .... | 40 | 18 | 12 | .... | 48 | 10.3 | PN | 0.83 | 2.60 | 0.60 | 0.65 | 0.33 | .... |
| 22 | 71 | 50 | 61 | 0.00 | 16.92 | 10.9 | 17.92 | 4.43 | 4.04 | .... | 142 | 58 | 42 | .... | 50 | 18 | 16 | .... | 66 | 10.9 | N | 1.14 | 1.80 | 1.65 | 1.00 | 0.39 | .... |
| 23 | 74 | 48 | 60 | 0.00 | 14.28 | 12.6 | 14.00 | 3.44 | 4.07 | .... | 88 | 30 | 14 | .... | 32 | 16 | 13 | .... | 62 | 7.6 | N | 0.58 | 1.20 | 1.45 | 0.98 | 0.30 | .... |
| 24 | 76 | 51 | 60 | 0.00 | 14.81 | 12.5 | 14.40 | 3.44 | 4.18 | 3.3 | 188 | 44 | 78 | 21 | 54 | 16 | 13 | 9 | 72 | 5.4 | N | 0.55 | 2.4 | 2.86 | 0.93 | 0.36 | 0.14 |
| 25 | 72 | 54 | 60 | 0.07 | 14.72 | 12.4 | 15.29 | 3.44 | 4.44 | 3.1 | 168 | 51 | 21 | 23 | 50 | 21 | 10 | 13 | 53 | 6.2 | PN | 0.68 | 1.3 | 2.80 | 2.18 | 0.67 | 1.14 |
| 26 | 70 | 59 | 61 | 0.10 | 14.12 | 13.1 | 13.78 | 3.44 | 4.00 | 3.5 | 136 | 26 | 19 | 17 | 51 | 22 | 11 | 13 | 52 | 6.0 | PN | 0.75 | 1.65 | 3.85 | 0.85 | 0.56 | 0.99 |
| 27 | 76 | 61 | 62 | 0.08 | 13.67 | 13.3 | 13.67 | 3.54 | 3.86 | 3.5 | 198 | 54 | 59 | 28 | 59 | 29 | 17 | 17 | .... | 4.8 | N | 0.80 | 2.7 | 2.40 | 1.72 | 1.23 | 1.20 |
| 28 | 76 | 56 | 61 | 0.00 | 13.53 | 13.4 | 13.53 | 3.38 | 4.00 | 3.5 | 180 | 34 | 44 | 20 | 60 | 26 | 17 | 13 | 70 | 3.6 | PN | 0.67 | 1.2 | 2.84 | 0.96 | 1.18 | 1.04 |
| 29 | 77 | 56 | 63 | 0.00 | 13.60 | 13.4 | 13.74 | 3.44 | 4.00 | 3.5 | 268 | 54 | 42 | 28 | 66 | 24 | 15 | 13 | 70 | 7.3 | N | 0.71 | 2.0 | 4.32 | 0.66 | 1.05 | .... |
| 30 | 87 | 65 | 62 | 0.57 | 14.35 | 12.7 | 14.77 | 3.33 | 4.43 | .... | 302 | 32 | 24 | .... | 48 | 21 | 13 | .... | .... | 8.1 | P | 0.62 | 1.7 | 1.61 | 1.66 | 0.79 | .... |
| 31 | 79 | 60 | 61 | 0.00 | 11.28 | 16.1 | 11.07 | 2.71 | 4.08 | .... | 210 | 52 | 25 | .... | 46 | 21 | 12 | .... | 85 | 7.4 | N | 0.45 | 2.35 | ..... | ..... | ..... | .... |
| Avge. | 70 | 50 | 58 | .... | 13.7 | 14.4 | 12.18 | 3.07 | 4.03 | 3.4 | 200 | 78 | 118 | 24 | 38 | 19 | 18 | 13 | 52 | 7.6 | ..... | 0.70 | 2.93 | 2.20 | 1.30 | 0.80 | 1.00 |

NOTE.—Operation of filters same as in April report. All septic tanks cleaned out May 11th, 12th and 13th.

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for June, 1909.

| Day of Month. | Temperature, Degrees, Fahr. | | | Rainfall, in in. | Volume pumped, in millions gal. per day. | Flow in septic tanks, av. period, in hrs. | Volume filtered, in millions gal. per day. | Filter area in service during application of sewage, in acres. | Av. rate of filtration during application of sewage, in millions gal. per acre per day. | Suspended Matter. Parts per million. | | | Oxygen Consumed. Parts per million. | | | Final Effluent. | | | | | Bacteria. Millions per c.c. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Air. | | | | | | | | | | | | | | | | | | Nitrogen. | | | | |
| | Max. | Min. | Sewage. | | | | | | | Screened sewage. | Septic effluent. | Filter effluent. | Screened sewage. | Septic effluent. | Filter effluent. | Chlorine, parts per million. | Dissolved oxygen, parts per million. | Putrescibility (odor) incubated 24 hrs. @ 37° C. | Nitrites, parts per million. | Nitrates, parts per million. | Screened sewage. | Septic effluent. | Filter effluent. |
| 1 | 80 | 66 | 63 | 0.00 | 10.6 | 17.2 | 10.5 | 2.50 | 4.18 | 234 | 44 | 29 | 43 | 21 | 12 | 53 | 7.6 | PN | 0.50 | 2.50 | ..... | ..... | ..... |
| 2 | 84 | 64 | 63 | 0.25 | 11.2 | 16.0 | 11.2 | 2.60 | 4.32 | 106 | 64 | 22 | 40 | 29 | 12 | 48 | 6.9 | P | 0.43 | 1.60 | ..... | ..... | ..... |
| 3 | 79 | 65 | 63 | 0.01 | 10.4 | 17.5 | 10.4 | 2.70 | 3.85 | 124 | 29 | 21 | 41 | 20 | 11 | 52 | 6.6 | PN | 0.41 | 1.40 | 3.20 | 0.96 | 0.92 |
| 4 | 79 | 66 | 65 | 0.07 | 11.0 | 16.7 | 10.9 | 2.50 | 4.36 | 236 | 34 | 28 | 47 | 20 | 11 | 51 | 7.2 | N | 0.50 | 2.70 | 9.00 | ..... | 0.72 |
| 5 | 84 | 63 | 65 | 0.07 | 11.9 | 15.4 | 12.0 | 2.70 | 4.44 | 188 | 32 | 21 | 46 | 18 | 9 | 54 | 7.1 | N | 0.58 | 2.50 | 6.91 | 1.76 | 0.95 |
| 6 | 84 | 56 | 65 | 0.00 | 11.7 | 15.5 | 11.9 | 2.90 | 4.10 | 96 | 43 | 49 | 16 | 15 | 12 | 58 | 6.8 | N | 0.56 | 2.50 | 4.00 | 1.35 | 0.92 |
| 7 | 88 | 64 | 65 | tr. | 11.2 | 16.4 | 10.9 | 2.60 | 4.20 | 164 | 36 | 57 | 44 | 13 | 12 | 52 | 8.0 | N | 0.94 | 3.76 | 8.20 | 1.54 | 0.70 |
| 8 | 90 | 64 | 65 | 0.67 | 11.7 | 15.6 | 12.0 | 2.50 | 4.80 | 174 | 31 | 102 | 42 | 19 | 16 | 53 | 7.3 | N | 0.58 | 3.22 | 6.16 | 1.97 | 0.70 |
| 9 | 92 | 64 | 67 | tr. | 12.5 | 14.5 | 12.5 | 2.60 | 4.80 | 208 | 38 | 81 | 39 | 20 | 14 | 29 | 7.1 | N | 0.60 | 2.30 | 2.76 | 1.84 | 0.48 |
| 10 | 84 | 64 | 66 | 0.24 | 12.5 | 14.7 | 12.5 | 2.90 | 4.30 | 194 | 31 | 148 | 30 | 14 | ..... | 32 | 7.9 | N | 0.68 | 3.07 | 3.00 | 1.98 | 0.33 |
| 11 | 77 | 60 | 67 | tr. | 13.5 | 13.6 | 13.5 | 3.25 | 4.16 | 334 | 38 | 52 | 31 | 15 | ..... | 20 | 8.0 | N | 0.70 | 1.90 | 0.72 | 1.00 | 0.32 |
| 12 | 81 | 56 | 67 | 0.00 | 12.9 | 8.6 | 12.6 | 3.10 | 4.05 | 184 | 53 | 38 | 29 | 13 | ..... | 32 | 9.0 | N | 0.85 | 3.00 | 4.92 | 0.76 | 0.28 |
| 13 | 88 | 56 | 66 | 0.00 | 13.3 | 8.0 | 13.4 | 2.90 | 4.60 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 14 | 84 | 56 | 66 | 0.00 | 12.7 | 8.6 | 12.7 | 3.10 | 4.10 | ..... | ..... | ..... | ..... | ..... | 15.6 | ..... | 8.3 | ..... | ..... | ..... | 4.65 | 5.72 | 2.63 | 0.52 |
| 15 | 83 | 57 | 67 | 0.00 | 14.7 | 7.5 | 14.7 | 3.20 | 4.60 | 204 | 50 | 48 | 56 | 22 | ..... | 51 | ..... | ..... | ..... | ..... | 3.50 | 4.25 | 1.98 | 0.65 |
| 16 | 80 | 56 | 65 | 0.00 | 13.4 | 8.2 | 13.1 | 3.30 | 4.00 | ..... | ..... | ..... | 59 | 36 | 14.8 | ..... | 7.6 | ..... | ..... | ..... | 2.22 | 3.50 | 1.77 | 0.70 |
| 17 | 84 | 54 | 67 | 0.30 | 14.0 | 7.8 | 14.2 | 3.30 | 4.25 | 366 | 55 | 93 | 74 | 36 | ..... | 57 | ..... | ..... | ..... | ..... | 2.32 | 1.46 | 1.50 | 0.66 |
| 18 | 76 | 52 | 67 | 0.00 | 12.6 | 8.6 | 12.5 | 3.30 | 3.75 | ..... | ..... | ..... | 56 | 36 | 19.0 | ..... | 7.1 | ..... | ..... | ..... | 3.72 | 2.04 | 0.83 | 0.40 |
| 19 | 81 | 47 | 66 | 0.00 | 13.0 | 8.5 | 12.8 | 3.00 | 4.30 | 96 | 43 | 124 | 51 | 34 | ..... | 61 | ..... | ..... | ..... | ..... | 2.72 | 3.18 | 1.71 | 0.74 |
| 20 | 90 | 49 | 65 | 0.00 | 12.2 | 9.0 | 12.5 | 2.90 | 4.30 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 21 | 87 | 66 | 68 | 0.32 | 15.4 | 7.2 | 15.3 | 3.45 | 4.44 | ..... | ..... | ..... | 72 | 33 | 15.4 | ..... | 5.8 | ..... | ..... | ..... | 5.02 | 1.42 | 1.02 |
| 22 | 83 | 68 | 70 | 0.03 | 17.0 | 6.5 | 16.9 | 3.75 | 4.50 | 284 | 78 | 62 | 59 | 36 | ..... | 61 | ..... | ..... | ..... | 2.95 | 2.15 | 1.00 | 0.20 |
| 23 | 84 | 67 | 70 | 1.01 | 16.7 | 6.7 | 16.4 | 3.65 | 4.48 | ..... | ..... | ..... | 63 | 40 | 12.2 | ..... | 6.6 | ..... | ..... | ..... | 1.98 | 0.78 | 0.19 |
| 24 | 87 | 66 | 68 | 0.12 | 16.0 | 7.0 | 15.8 | 3.55 | 4.45 | 282 | 67 | 35 | 52 | 28 | ..... | 64 | ..... | ..... | ..... | 2.38 | 1.50 | 0.63 | 0.27 |
| 25 | 90 | 66 | 69 | 0.49 | 15.7 | 7.0 | 15.7 | 3.55 | 4.42 | ..... | ..... | ..... | 56 | 25 | 13.7 | ..... | 6.8 | ..... | ..... | ..... | 3.32 | 1.03 | 0.39 |
| 26 | 91 | 67 | 69 | 0.00 | 15.8 | 6.9 | 15.8 | 3.45 | 4.58 | 344 | 101 | 33 | 44 | 24 | ..... | 57 | ..... | ..... | ..... | 3.30 | 1.44 | 0.57 | 0.28 |
| 27 | 94 | 73 | 69 | 0.23 | 15.1 | 7.3 | 15.2 | 3.65 | 4.20 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 28 | 92 | 71 | 70 | 0.07 | 14.8 | 7.5 | 14.8 | 3.55 | 4.20 | ..... | ..... | ..... | 41 | 26 | 11.8 | ..... | 7.3 | PN | ..... | ..... | 1.55 | 0.80 | 0.25 |
| 29 | 92 | 71 | 71 | 0.00 | 14.5 | 7.5 | 14.2 | 3.50 | 4.05 | 242 | 70 | 32 | 39 | 19 | ..... | 54 | ..... | N | 3.65 | 2.11 | 0.58 | 0.28 |
| 30 | 89 | 60 | 71 | 0.00 | 13.9 | 7.7 | 14.2 | 3.15 | 4.50 | ..... | ..... | ..... | 38 | 27 | 10.4 | ..... | 7.7 | PN | ..... | ..... | 3.26 | 0.76 | 0.26 |
| Avge. | 86 | 61 | 67 | .... | 13.4 | 10.6 | 13.4 | 3.10 | 4.30 | 214 | 49 | 56 | 46 | 24 | 13 | 49 | 7.3 | ..... | ..... | ..... | 3.65 | 1.29 | 0.52 |

NOTE.—Until June 13th analyses of filter effluent were made on the combined effluent of all filters.

Beginning June 14th Filter 7 has been operated on a 15-min. schedule and Filter 8 on a schedule alternating 6 hours run and 6 hours rest; tests for suspended matter, since that time, have been made on the combined effluent of Filters 7 and 8; the oxygen consumed has been determined from the effluent from Filter 7, and the bacterial content is the average of the samples taken from Filters 7 and 8.

Between June 13th and June 28th, putrescibility tests by odor were omitted.

The settling basins were out of service, on account of the construction of the retaining walls.

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for July, 1909.

| Day of Month. | Temperature, Degrees, Fahr. | | | Rainfall, in in. | Volume pumped, in millions gal. per day. | Flow in septic tanks, av. period, in hrs. | Volume filtered, in millions gal. per day. | Filter area in service during application of sewage, in acres. | Av. rate of filtration during application of sewage, in mill. gal. per acre per day. | Analytical Results, Parts per Million. | | | | | | | | | | Bacteria. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Susp'd Matter. | | | Oxygen Cons'd. | | | Final Effluent. | | | | | | |
| | Air. | | | | | | | | | | | | | | | | | | | Millions per c. c. | | |
| | Max. | Min. | Sewage. | | | | | | | Screened sewage. | Septic effluent. | Filter effluent. | Screened sewage. | Septic effluent. | Filter effluent. | Chlorine. | Dissolved oxygen. | Putrescibility (odor) incubated 24 hrs. @ 37° C. | Nitrates. | Screened sewage. | Septic effluent. | Filter effluent. |
| 1 | 95 | 64 | 70 | 0.00 | 14.82 | 7.4 | 14.63 | 3.55 | 4.10 | 194 | 89 | 32 | 42 | 28 | ..... | 58 | ..... | PN | 2.30 | 3.08 | 0.59 | 0.19 |
| 2 | 93 | 64 | 69 | 0.60 | 15.73 | 6.9 | 15.80 | 3.45 | 4.60 | ..... | ..... | ..... | 45 | 32 | 13.9 | ..... | 6.4 | PN | ..... | 2.02 | 0.61 | 0.15 |
| 3 | 77 | 64 | 70 | tr. | 14.99 | 7.3 | 14.95 | 3.45 | 4.30 | 162 | 98 | 47 | 47 | 30 | ..... | 76 | ..... | PN | 2.62 | 1.76 | 0.44 | 0.18 |
| 4 | 76 | 65 | 69 | 0.00 | 13.08 | 5.6 | 13.23 | 3.45 | 3.85 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 5 | 70 | 58 | 69 | 0.09 | 14.07 | 5.5 | 14.00 | 3.40 | 4.10 | ..... | ..... | ..... | 56 | 34 | 14.3 | ..... | 8.0 | N | ..... | 1.29 | 0.52 | 0.19 |
| 6 | 82 | 58 | 68 | 0.01 | 9.94 | 7.6 | 9.90 | 3.30 | 3.00 | 198 | 106 | 43 | 67 | 45 | 15.4 | 69 | 6.6 | PN | 3.40 | 1.21 | 0.60 | 0.29 |
| 7 | 89 | 65 | 70 | 0.00 | 18.40 | 4.3 | 18.37 | 3.40 | 5.40 | ..... | ..... | ..... | 66 | 47 | 15.0 | ..... | 7.0 | PN | ..... | 2.50 | 0.94 | 0.41 |
| 8 | 89 | 66 | 70 | 0.00 | 14.04 | 5.5 | 14.07 | 3.45 | 4.10 | 160 | 114 | 42 | 64 | 47 | 12.3 | 58 | 6.2 | PN | 1.85 | 5.77 | 1.12 | 0.40 |
| 9 | 90 | 65 | 68 | 0.00 | 8.44 | 8.2 | 8.62 | 2.30 | 3.70 | ..... | ..... | ..... | 44 | 44 | 11.4 | ..... | 6.2 | PN | ..... | 2.78 | 0.89 | 0.14 |
| 10 | 86 | 73 | 63 | 0.00 | 5.16 | 14.4 | 5.00 | 1.40 | 3.60 | 160 | 104 | 80 | 24 | 37 | ..... | 49 | ..... | PN | 3.25 | 0.80 | 0.45 | 0.28 |
| 11 | 78 | 69 | 63 | 0.16 | 5.74 | 13.5 | 5.92 | 1.50 | 3.95 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 12 | 86 | 67 | 64 | 1.11 | 8.08 | 9.5 | 8.08 | 1.65 | 4.90 | ..... | ..... | ..... | 32 | 26 | 23 | ..... | 5.8 | PN | ..... | 0.66 | 0.25 | 0.08 |
| 13 | 87 | 69 | 66 | 0.38 | 9.38 | 8.0 | 9.32 | 2.15 | 4.35 | 122 | 84 | 197 | 29 | 27 | 23 | 28 | 7.1 | N | 4.00 | 0.76 | 1.00 | 0.35 |
| 14 | 85 | 71 | 65 | tr. | 9.35 | 8.0 | 9.50 | 2.05 | 4.60 | ..... | ..... | ..... | 29 | 28 | 38 | ..... | 5.4 | PN | ..... | 1.04 | 0.78 | 0.27 |
| 15 | 90 | 67 | 68 | 0.57 | 9.13 | 8.0 | 6.86 | 1.55 | 4.40 | 62 | 106 | 186 | 24 | 26 | 24 | ..... | 7.1 | N | 3.65 | ..... | ..... | ..... |
| 16 | 82 | 66 | 67 | 0.23 | 9.40 | 8.0 | 9.36 | 2.00 | 4.70 | ..... | ..... | ..... | 23 | 17 | 51 | ..... | 6.2 | N | ..... | 0.65 | 0.22 | 0.15 |
| 17 | 82 | 63 | 67 | 0.00 | 9.65 | 7.7 | 9.70 | 2.30 | 4.20 | 100 | 44 | 259 | 19 | 14 | ..... | 31 | ..... | N | 4.05 | 0.36 | 0.24 | 0.07 |
| 18 | 82 | 51 | 68 | 0.01 | 9.50 | 8.1 | 9.30 | 2.30 | 4.00 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 19 | 78 | 57 | 69 | 0.00 | 10.00 | 7.7 | 10.10 | 2.30 | 4.40 | ..... | ..... | ..... | 29 | 14 | 24.3 | ..... | 7.2 | N | ..... | 0.72 | 0.08 | 0.03 |
| 20 | 87 | 64 | 68 | 0.00 | 10.60 | 7.2 | 10.50 | 2.20 | 4.80 | 104 | 43 | 118 | 33 | 23 | 20.6 | 40 | 7.6 | N | 3.32 | 1.47 | 0.38 | 0.13 |
| 21 | 82 | 65 | 68 | 0.00 | 10.50 | 7.0 | 10.70 | 2.20 | 4.90 | ..... | ..... | ..... | 23 | 21 | 25.2 | ..... | 7.3 | N | ..... | 0.67 | 0.55 | 0.19 |
| 22 | 86 | 68 | 68 | 0.40 | 10.50 | 7.2 | 10.40 | 2.10 | 5.00 | 52 | 18 | 43 | 42 | 21 | 20.6 | 40 | 6.9 | N | 3.80 | 0.94 | 0.66 | 0.13 |
| 23 | 66 | 59 | 68 | 0.03 | 10.70 | 7.0 | 10.70 | 2.20 | 4.90 | ..... | ..... | ..... | 37 | 21 | 20.3 | ..... | 7.7 | N | ..... | 0.68 | 0.52 | 0.15 |
| 24 | 85 | 65 | 68 | 0.00 | 10.30 | 7.4 | 10.20 | 2.20 | 4.60 | 60 | 39 | 55 | 28 | 18 | ..... | 35 | ..... | N | 3.85 | 0.63 | 0.33 | 0.06 |
| 25 | 85 | 65 | 66 | 0.00 | ..... | 8.7 | 9.00 | 2.50 | 3.60 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 26 | 80 | 65 | 66 | 0.02 | ..... | 9.4 | 8.80 | 1.95 | 4.50 | ..... | ..... | ..... | 28 | 15 | 12.4 | ..... | 8.0 | N | ..... | 0.62 | 0.30 | 0.06 |
| 27 | 77 | 72 | 66 | 0.02 | ..... | 8.0 | 8.80 | 2.05 | 4.30 | 85 | 53 | 51 | 39 | 29 | 14.5 | 40 | 7.1 | N | 4.40 | 1.04 | 0.58 | 0.06 |
| 28 | 87 | 62 | 68 | 0.00 | ..... | 7.5 | 9.70 | 2.05 | 4.70 | ..... | ..... | ..... | 32 | 40 | 14.5 | ..... | 6.4 | N | ..... | 1.25 | 0.62 | 0.17 |
| 29 | 90 | 65 | 69 | 0.08 | ..... | 8.2 | 8.90 | 2.05 | 4.30 | 74 | 73 | 51 | 53 | 30 | 15.7 | 42 | 6.5 | N | 3.57 | 0.78 | 0.36 | 0.07 |
| 30 | 93 | 70 | 69 | 0.18 | ..... | 8.0 | 9.30 | 1.95 | 4.80 | ..... | ..... | ..... | 34 | 30 | 13.2 | ..... | 6.7 | N | ..... | 0.75 | 0.50 | 0.09 |
| 31 | 85 | 60 | 69 | tr. | ..... | 8.3 | 9.20 | 2.05 | 4.50 | 70 | 63 | 67 | 33 | 34 | ..... | 50 | ..... | N | 3.98 | 0.87 | 0.40 | 0.07 |
| Avge. | 84 | 65 | 67 | .... | 10.90 | 7.9 | 10.42 | 2.40 | 4.36 | 115 | 74 | 91 | 38 | 29 | 20.1 | 47 | 6.8 | ..... | 3.43 | 1.35 | 0.54 | 0.17 |

NOTE.—Chlorine, oxygen consumed, dissolved oxygen, and putrescibility determinations in the filter effluent are made on samples taken from the effluent from Filter 7. Suspended matter in the filtered sewage is determined from composite samples taken from Filters 7 and 8, and the nitrites and nitrates and the bacterial content in the filtered sewage are the averages of analyses from Filters 7 and 8. Filter 7 has been operated on the 15-min. schedule, and Filter 8 on the 6-hour schedule. The divisions of the septic tanks in service have been: July 1st to 3d, inclusive, Nos. 2, 3, 4, and 6. July 4th to 14th, inclusive, Nos. 4 and 6. July 15th to 31st, inclusive, Nos. 4 and 5. The settling basins were out of service throughout the month, on account of the construction of the retaining walls. On July 9th, the intercepting sewer was shut off at Mound Street, all sewage above this point flowing direct to the river. On July 12th, river water was admitted to the pump suctions with the intent to keep the flow of sewage at about 10 000 000 gal. per day.

TABLE 16.—SEWAGE PURIFICATION WORKS.—(*Continued.*)—Records of Operation for August, 1909.

| Day of Month. | Temperature, Degrees, Fahr. | | | Rainfall, in inches. | Flow in septic tanks, av. period, in hours. | Volume filtered, in mill. of gal. per day. | Filter area in service during application of sewage, in acres. | Av. rate of filtration during application of sewage, in millions of gallons per acre per day. | Flow in settling basin, av. period, in hrs. | Analytical Results, Parts per Million. | | | | | | | | | | | Bacteria. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Suspended Matter. | | | | Oxygen Cons'd. | | | | Final Effluent. | | | | | Millions per c. c. | | | |
| | Air. | | Sewage. | | | | | | | Screened sewage. | Septic effluent. | Filter effluent. | Settling bas. in effluent. | Screened sewage. | Septic effluent. | Filter effluent. | Settling bas. in effluent. | Chlorine. | Dissolved oxygen. | Putrescibility (odor) incubated 24 hrs. @ 37° C. | Nitrates. | Screened sewage. | Septic effluent. | Filter effluent. | Settling bas. in effluent. |
| | Max. | Min. | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 95 | 72 | 68 | 0.00 | 8.1 | 9.04 | 1.95 | 4.6 | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 2 | 95 | 72 | 68 | 0.00 | 8.6 | 9.04 | 1.85 | 4.9 | .... | ..... | ..... | ..... | ..... | 35 | 26 | 16.0 | .... | ..... | 7.3 | N | ..... | 0.65 | 0.16 | 0.033 | .... |
| 3 | 93 | 66 | 68 | 0.00 | 8.4 | 8.56 | 1.85 | 4.6 | .... | 61 | 52 | 62 | .... | 46 | 33 | 14.3 | .... | 45 | 6.8 | N | 4.20 | 0.54 | 0.25 | 0.063 | .... |
| 4 | 86 | 69 | 68 | 0.00 | 8.3 | 9.14 | 1.90 | 4.8 | .... | ..... | ..... | ..... | ..... | 47 | 35 | 14.1 | .... | ..... | 6.9 | N | ..... | 0.76 | 0.41 | 0.079 | .... |
| 5 | 85 | 68 | 68 | 0.02 | 8.2 | 9.37 | 2.05 | 4.5 | .... | ..... | ..... | ..... | ..... | 49 | 32 | 19.9 | .... | 48 | 6.5 | N | 3.50 | 1.18 | 0.46 | 0.170 | .... |
| 6 | 93 | 67 | 69 | 0.00 | 8.0 | 9.04 | 2.00 | 4.5 | .... | 80 | 67 | 94 | .... | 36 | 35 | 24.9 | .... | ..... | 6.0 | N | ..... | 1.05 | 0.61 | 0.170 | .... |
| 7 | 94 | 70 | 69 | 0.00 | 7.7 | 9.71 | 2.05 | 4.7 | .... | ..... | ..... | ..... | ..... | 45 | 33 | ..... | .... | 44 | ..... | N | 4.10 | 1.16 | 0.44 | 0.120 | .... |
| 8 | 95 | 70 | 69 | 0.00 | 8.1 | 9.16 | 1.75 | 5.2 | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 9 | 90 | 75 | 70 | 0.00 | 8.1 | 9.16 | 1.85 | 4.9 | .... | 76 | 46 | 100 | .... | 29 | 37 | 14.4 | .... | ..... | 6.3 | N | ..... | 0.54 | 0.14 | 0.062 | .... |
| 10 | 89 | 65 | 69 | 0.09 | 8.4 | 8.93 | 1.95 | 4.6 | .... | 63 | 60 | 213 | .... | 41 | 33 | 30.6 | .... | 42 | 5.9 | N | 6.18 | 0.64 | 0.31 | 0.077 | .... |
| 11 | 91 | 67 | 69 | 0.00 | 7.8 | 9.28 | 1.67 | 4.0 | .... | ..... | ..... | ..... | ..... | 30 | 33 | 17.1 | .... | ..... | 6.0 | N | ..... | 1.00 | 0.50 | 0.120 | .... |
| 12 | 75 | 71 | 69 | 0.15 | 8.3 | 9.06 | 1.75 | 5.2 | .... | 79 | 64 | 120 | .... | 53 | 37 | 17.0 | .... | 43 | 6.5 | N | 4.18 | 0.96 | 0.79 | 0.165 | .... |
| 13 | 82 | 75 | 70 | 0.00 | 8.1 | 9.13 | 1.95 | 4.7 | .... | ..... | ..... | ..... | ..... | 37 | 37 | 16.8 | .... | ..... | 6.9 | N | ..... | 1.08 | 0.66 | 0.116 | .... |
| 14 | 86 | 75 | 70 | 0.23 | 8.2 | 9.11 | 1.85 | 4.9 | .... | 70 | 31 | 94 | .... | 35 | 28 | ..... | .... | 48 | ..... | N | ..... | 1.32 | 0.76 | 0.169 | .... |
| 15 | 83 | 67 | 69 | 1.69 | 7.9 | 9.71 | 2.05 | 4.7 | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 16 | 88 | 70 | 71 | 0.14 | 6.1 | 12.12 | 2.25 | 5.4 | .... | 305 | 55 | 67 | .... | 34 | 13 | 12.7 | .... | 29 | 7.5 | N | 5.93 | 0.37 | 0.10 | 0.018 | .... |
| 17 | 82 | 65 | 72 | tr. | 5.5 | 13.20 | ..... | ..... | .... | 153 | 118 | ..... | ..... | 17 | 14 | ..... | .... | 10 | ..... | ..... | ..... | 0.165 | 0.10 | ..... | ..... |
| 18 | 77 | 65 | 69 | 0.00 | 8.1 | 9.36 | ..... | ..... | .... | ..... | ..... | ..... | ..... | 25 | 23 | ..... | .... | ..... | ..... | N | ..... | ..... | ..... | ..... | ..... |
| 19 | 87 | 62 | 69 | 0.00 | 7.2 | 10.88 | 2.60 | 4.2 | .... | 127 | 42 | 97 | .... | 33 | 21 | 11.2 | .... | 43 | 7.3 | N | 6.15 | 0.80 | 0.27 | 0.052 | .... |
| 20 | 81 | 64 | 70 | 0.00 | 6.3 | 12.51 | 2.80 | 4.5 | .... | ..... | ..... | ..... | ..... | 31 | 23 | 11.7 | .... | ..... | 7.0 | N | ..... | 0.67 | 0.26 | 0.050 | .... |
| 21 | 85 | 64 | 69 | 0.00 | 6.4 | 12.13 | 2.70 | 4.5 | .... | 104 | 42 | 17 | .... | 29 | 25 | ..... | .... | 45 | ..... | N | 3.70 | 0.24 | 0.15 | 0.035 | .... |
| 22 | 91 | 49 | 69 | 0.00 | 7.4 | 10.6 | 2.35 | 4.5 | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 23 | 94 | 58 | 69 | 0.00 | 7.1 | 9.8 | 2.25 | 4.4 | .... | ..... | ..... | ..... | ..... | 50 | 34 | ..... | .... | ..... | 8.4 | N | ..... | 0.98 | 0.60 | 0.110 | .... |
| 24 | 93 | 68 | 68 | 0.00 | 8.0 | 9.6 | 2.35 | 4.1 | .... | 140 | 40 | 20 | .... | ..... | 45 | ..... | .... | 50 | 6.8 | NP | 3.10 | 1.65 | 0.81 | 0.150 | .... |
| 25 | 93 | 74 | 70 | 0.05 | 7.8 | 9.6 | 2.35 | 4.1 | .... | ..... | ..... | ..... | ..... | 66 | 39 | 20.0 | 17 | ... | 5.5 | N | 2.50 | 2.20 | 0.65 | 0.250 | 0.16 |
| 26 | 93 | 75 | 70 | 0.04 | 7.9 | 9.6 | 2.25 | 4.3 | .... | 160 | 50 | 25 | 25 | 52 | 42 | 24.0 | 19 | 56 | 5.5 | N | 2.20 | 1.08 | 0.55 | 0.140 | 0.48 |
| 27 | 92 | 68 | 70 | 0.09 | 8.1 | 9.4 | 2.35 | 4.0 | .... | ..... | ..... | ..... | ..... | 58 | 37 | 21.0 | 17 | ... | 5.0 | N | 2.00 | 0.90 | 0.42 | 0.120 | 0.42 |
| 28 | 92 | 75 | 70 | 0.02 | 7.8 | 9.9 | 2.25 | 4.4 | .... | 195 | 35 | 25 | 10 | 70 | 45 | 22.0 | 20 | 59 | 4.8 | N | 2.00 | 1.40 | 0.88 | 0.280 | 0.47 |
| 29 | 85 | 61 | .... | 0.01 | 8.5 | 8.94 | 2.25 | 4.0 | 5.4 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 30 | 86 | 55 | .... | 0.00 | 8.0 | 9.74 | 2.35 | 4.15 | 4.9 | ..... | ..... | ..... | ..... | 54 | 34 | 18.0 | 15 | .... | 6.8 | N | 3.70 | 0.56 | 0.23 | 0.060 | 0.08 |
| 31 | 83 | 49 | .... | 0.00 | 8.0 | 9.56 | 2.25 | 4.25 | 5.0 | 145 | 65 | 35 | 25 | 61 | 44 | 23.0 | 20 | 59 | 4.7 | P | 2.50 | 1.45 | 0.85 | 0.170 | 0.55 |
| Avge. | 88 | 67 | 69 | .... | 7.8 | 9.82 | 2.13 | 4.50 | 5.1 | 126 | 55 | 75 | 20 | 42.5 | 32 | 18.3 | 18 | 44 | 6.4 | ..... | 3.70 | 0.93 | 0.46 | 0.115 | 0.36 |

NOTE.—*Septic Tanks:* Nos. 4 and 6 in service to Aug. 11th. Aug. 11th, Nos. 4 and 6 put out of service, and Nos. 1 and 5 drained and put into service. Aug. 16th, Nos. 1 and 5 out; Nos. 4 and 6 in; No. 1 partially cleaned out. Aug. 17th. No. 5 thoroughly cleaned out; No. 2 partially cleaned out. Aug. 18th, Nos. 1 and 5 in; Nos. 4 and 6 out. North settling basin put into service Aug. 23d.

seem that during the first few months of operation the test for putrescibility was more rigorously applied than was the case at the testing station and at places elsewhere, thus placing some of the results secured at the Columbus works in a somewhat unfavorable light. Exhaustion of free dissolved oxygen in the undiluted samples of the final effluent in the incubator tests was practically taken as denoting putrescibility, whereas more oxygen could be obtained from the nitrites and nitrates before actual putrefaction would result.

TABLE 17.—RESULTS OBTAINED IN THE EXPERIMENTAL INVESTIGATION WITH TEST SPRINKLING FILTER C.

| | | | Parts per million. |
|---|---|---|---|
| Suspended Matter | Screened sewage. | | 209 |
| | Septic effluent. | | 82 |
| | Filter effluent. | | 57 |
| Oxygen Consumed | Screened sewage. | | 51 |
| | Septic effluent. | | 37 |
| | Filter effluent. | | 18 |
| Nitrogen | Filter effluent. | As nitrites. | 0.69 |
| | | As nitrates. | 3.10 |
| Putrescibility | Filter effluent. | Undiluted. | N. |
| | | 1 to 1. | N. |
| | Final effluent. | Undiluted. | N. |
| | | 1 to 1. | N. |
| | | | Millions per c.c. |
| Bacteria | Screened sewage. | | 3.6 |
| | Septic effluent. | | 3.3 |
| | Filter effluent. | | 1.0 |

## SUMMARY OF COST OF ENGINEERING.

As the design and construction of the water and sewerage work was directed from one office, it has been impossible to apportion exactly to each certain of the items in the cost of engineering, although the figures given are sufficiently close for all practical purposes. A summary of the cost of engineering, however, may be of interest, and is therefore given in Table 18.

TABLE 18.—SUMMARY OF COST OF ENGINEERING.

| Work. | Cost of work. | Cost of Engineering. | | | | |
|---|---|---|---|---|---|---|
| | | Pay-roll. | Supplies. | Expenses. | Total. | Percentage. |
| Scioto River Storage Dam and Reservoir | $489 350 | $27 540 | $3 560 | $2 230 | $33 330 | 6.81 |
| Scioto River Pumping Station and Water Purification Works and work connected therewith | 1 237 620 | 84 340 | 6 120 | 5 490 | 95 950 | 7.75 |
| Sewage improvements | 1 198 180 | 90 820 | 6 450 | 10 280 | 107 550 | 8.98 |
| Totals | $2 925 150 | $202 700 | $16 130 | $18 000 | $236 830 | 8.10 |
| Land for Scioto River Storage Dam and Reservoir | $150 850 | | | | | |
| Engineering | 236 830 | | | | | |
| GRAND TOTAL OF COST | $3 312 830 | | | | | |

## ENGINEERING ORGANIZATION.

The engineering work was organized as practically a separate branch of the engineering department of the Board of Public Service. At the time the work was started, Julian Griggs, M. Am. Soc. C. E., was the Chief Engineer of the Department, having occupied that position for several years previous to the commencement of this work, and it is a pleasure for the writer to state that the City of Columbus is indebted most to Mr. Griggs for bringing about and carrying forward these two improvements. Mr. Griggs paved the way, and it was due to his foresight and perseverance, in the face of criticism, long since silenced, that the work was successfully started; too much credit cannot be given him. Mr. Griggs was succeeded in 1906 by Mr. Henry Maetzel, who has ably followed the policies of his predecessor. Rudolph Hering and George W. Fuller, Members, Am. Soc. C. E., have acted throughout as Consulting Engineers, and to them great credit is due for their hearty co-operation.

The experimental investigations were ably carried out by George A. Johnson, Assoc. M. Am. Soc. C. E., assisted by William R. Copeland, Assoc. Am. Soc. C. E., Chief Bacteriologist, Mr. A. Elliot Kimberly, Chief Chemist, and Mr. George P. Shute, Assistant Engineer.

Mr. F. B. Edwards was Resident Engineer in charge of the construction of the dam and reservoir; George E. Howe, M. Am. Soc. C. E.,

Resident Engineer in charge of the construction of the Scioto River pumping station, water purification works, and force mains; Mr. Edward A. Kemmler, Resident Engineer in charge of the construction of the sewage pumping stations, purification works, and sewerage work; Mr. Walter W. Jackson, Mechanical Engineer in charge of the mechanical equipment, and Messrs. George E. Howe, and J. William Link, and Arthur J. Decker, Jun. Am. Soc. C. E., in charge of the office work, to whom the successful completion of the work is in no small measure due. The writer was in direct charge of the design and construction of the work, with the titles, successively, of Engineer of Design, Principal Assistant Engineer, and Engineer in Charge.

The operation of the two works has been and is still in charge of Mr. Jackson, as Engineer of Water Supply and Sewage Disposal, assisted by Mr. Copeland, as Chief Chemist and Bacteriologist at the water purification works, and Mr. Clarence B. Hoover, as Chief Chemist and Bacteriologist at the sewage purification works, and to them the credit is due for the successful operation of the works.

In closing, the writer wishes to acknowledge his indebtedness for the hearty co-operation given him, not only by all those connected with the engineering organization, but by the members of the several Boards of Public Service under whose direction the work was done, and the numerous other city officials with whom he came in contact, and who, practically without exception, did everything within their power to further the carrying out of the work.

# DISCUSSION.

Mr. Ellms. JOSEPH W. ELLMS, ESQ.* (by letter).—The very complete tables of cost of construction submitted by Mr. Gregory are of much value. The total and unit costs relating to the Water Purification Works were of particular interest to the writer in connection with a similar table compiled from the costs of construction of the Cincinnati Filtration Plant. It is obvious that no strict comparison of the costs of similar parts of these two plants is justifiable, since each was designed to meet local conditions. At Cincinnati the plant was required to clarify and purify a turbid water; at Columbus the same conditions were to be met, but, in addition, the water was to be softened. Apparently, the latter function was considered as governing the design of the works at Columbus.

Table 19, showing the costs of construction for the Cincinnati Filtration Plant, is submitted as a contribution to the general subject, and may be of interest to engineers designing and building plants of this type.

TABLE 19.—TOTAL AND UNIT COSTS OF MAIN FEATURES OF WORK DONE IN CONSTRUCTION OF WATER PURIFICATION WORKS AT CINCINNATI, OHIO.

Capacity of Plant: 112 Million Gallons in 24 Hours.

| Work. | Total cost. | Cost per million gallons of capacity for 24 hours. |
|---|---|---|
| Preparation of grounds | $33 359.67 | $297.85 |
| Pipe lines between settling reservoirs and head-house | 55 354.77 | 494.24 |
| Head and chemical house | 141 989.85 | 1 267.77 |
| Coagulation basins, gate houses and pipe lines | 304 913.05 | 2 722.44 |
| Filters, filter house, piping, sand and gravel | 592 112.30 | 5 286.71 |
| Piping, valves and gate-house between filters and clear-water reservoir | 29 701.91 | 265.20 |
| Clear-water reservoir | 121 332.39 | 1 083.59 |
| Total | $1 278 793.94 | $11 417.80 |

At Columbus, the unit costs per million gallons of capacity in 24 hours appear to be considerably greater for the settling basins and mixing tanks combined, than for the coagulation basins at Cincinnati. The figures for the Columbus tanks and basins are $7 100 per million gallons of capacity, as compared with $2 722 at Cincinnati. In a general way, these parts of the two plants correspond; but it should not be forgotten that at Columbus more elaborate baffling

* Superintendent, Cincinnati Filtration Plant.

of tanks and basins, more divisions of the flow of the raw and treated waters, and more places for the primary and secondary applications of chemical solutions were needed and provided for, than were required at Cincinnati. The greater combined unit costs of the head-house, lime-saturator house, storage-house, wash-water tank, offices and laboratories at Columbus, than for the corresponding head-house, chemical-house, wash-water tank, offices, and laboratories at Cincinnati, are similarly explained by the necessity for designing a plant for softening, as well as for clarifying and purifying the water. The combined unit costs for the items noted above for the Columbus plant amount to $3 784, as compared with $1 268 for the Cincinnati plant. Mr. Ellms.

The filters and piping in the Cincinnati plant cost more per million gallons of capacity than did those at Columbus. The figures for Columbus, which include the air-washing equipment, are $3 540, as compared with $5 287 for Cincinnati. However, the filtered-water reservoir at Columbus cost more than that at Cincinnati. The figures for the Columbus plant are $3 280 per million gallons, and for the Cincinnati plant, $1 084. At the latter plant, the clear-water reservoir is a separate uncovered reservoir, while at Columbus, it is directly under the filter tanks, which latter form a protecting roof. Virtually, no great difference in costs exists, if the cost of the filters, piping, and clear-water reservoir of each plant be combined and then compared.

The cost per million gallons of capacity for the whole purification plant at Columbus is stated to be $17 750, which amount does not include engineering; the corresponding figure for the Cincinnati plant, as shown above, is $11 418, and this also excludes the cost of engineering. The difference of more than $6 000 per million gallons of capacity is doubtless due to the additional requirement demanded by the local conditions at Columbus, that is, for the softening of a very hard water, and one which is at times subject to rapid fluctuations in its physical characteristics.

JULIAN GRIGGS, M. AM. SOC. C. E. (by letter).—This descriptive record, with the liberal illustrations showing the details of construction of the improved water and sewage works at Columbus, Ohio, forms a valuable addition to the rapidly growing accumulation of literature pertaining to municipal sanitation. Therefore, it should prove welcome to all who are interested in the subject, and especially to that wide circle of progressive engineers and city officials who since 1904 have followed more or less closely, by pilgrimage or otherwise, the development here being realized. Mr. Griggs.

Columbus is to be congratulated on having works in which the highest state of the art of water and sewage purification was represented at the time they were designed.

Mr. Griggs.

The mechanical execution of the work was also of a high order of excellence, and reflects great credit on the contractors and the engineering organization in responsible charge of its construction.

The elasticity of the design is proving of value in affording a wide range for varying the details of operation and thus permitting sundry experiments by the chemists in charge, which will ultimately add to the knowledge on many obscure questions of rates and efficiency, a feature which the writer hopes to see emphasized in the discussion on this paper.

One defect in the sewerage system and sewage purification works to be regretted is in the sand-catching appliances. It seems to the writer that some mechanical device for cleaning and keeping clean the sand-catcher at the main sewage pumping station should have been installed, for the reason that dependence on hand-cleaning has been found to be unreliable. Soon after the operation of the pumping station was begun, the sand-catcher filled to the flow line of the sewer. Since then all detritus arriving in the sewer has been carried forward into the sump chamber where it clogged the sewage-level indicators, and the portion which remained has had to be removed therefrom by hand-cleaning at more or less frequent intervals. Probably half of the detritus carried to the station in the sewage passed the pumps and was later deposited in the primary septic tanks, where, forming layers over the septic sludge, it confined the gases of decomposition and greatly increased the violence of the ebullitions, thus complicating their action. It still remains to be disposed of.

In this connection it may be of interest to state that the interceptors, some twenty in number, on the intercepting sewer are for the most part only pits, 1 or 2 ft. in depth, in the bottom of each combined sewer, with pipes varying from 6 to 15 in. in diameter leading from the pits to the intercepting sewer beneath the combined sewer at the point of crossing. It is apparent, therefore, that each intercepting pit acts as a sand-catcher for detritus and quickly conveys it to the intercepting sewer. This condition is somewhat mitigated by the fact that in flood flows the smaller interceptors become clogged, and, in that event, a portion of the detritus is carried past the interceptor to the river outlet of the combined sewer.

Three of the interceptors are provided with automatic gates controlled by floats which close the connection to the intercepting sewer at times of storm flow, when, presumably, the greatest proportion of the detritus would be carried in the sewage. These devices have served the purpose intended. It may be that now, however, a new condition has been introduced, which renders them less effective than formerly. The new condition is the daily use of compressed air street flushers, first introduced in 1904; and now, weather permitting, 3 miles of 30-ft. streets, or an equivalent area, are washed daily. These flushers simu-

late the condition of a heavy shower for the area over which they operate, and carry into the sewer catch-basins and the sewer itself a large quantity of detritus. In the area flushed there are 518 street catch-basins, mostly of the standard pit type, 3½ ft. in diameter, and 1½ ft. deep below the siphon outlets; but 9% of these catch-basins are direct inlets furnished with the so-called Palmer valves. As repairs are needed, these basins are being gradually changed to the standard form with pits. Mr. Griggs.

The intercepting sewer is 6.8 miles long and from 2½ to 6 ft. in diameter, with a grade of 1 per 3 000 at its largest diameter, giving a velocity of 2.3 ft. per sec. It was first put into operation in August, 1894; five years later, in September, 1899, a cleaning of it was begun, which was continued until June, 1900, whereby deposits of from 10 to 15 in. in depth were removed from about 2.4 miles of sewer at a cost of $1.78½ per cu. yd., or a total cost of $6 564.81. Nine years later, in July, 1909, deposits upward of 3 ft. in depth having accumulated, a second cleaning was begun and is being continued.

While the intercepting sewer is being hand-cleaned it is necessary to close the interceptors and divert the raw sewage into the river, fouling the same, and thus defeating for a time the purpose for which the sewage purification works have been constructed.

The cleaning of the intercepting sewer with sewage accumulated under a considerable head in manholes at frequent intervals and suddenly released through quick-opening gates has been proposed, but while this method is effective in small sewers, it is doubtful whether it would be in sewers of large diameter unless the accumulation of sewage was augmented by storage greatly in excess of manhole capacities.

The fact that the intercepting sewer is about 5 ft. lower than low stages of water in adjacent streams suggests a connection with the same for flushing purposes, and for the upper end of the sewer such a provision should prove of benefit.

Whenever the intercepting sewer has been cleaned the sand has been found cemented in layers with tar which has escaped from the gas-works of the Ohio Penitentiary. An interceptor in the street, on the house sewer from the penitentiary, was built in 1900 and was cleaned five times in that year of from 6 to 8 bbl. of tar at each cleaning. It may be that in the changes occurring since in State and city officials, this provision for preventing tar from entering the sewers has been overlooked.

The advisability of constructing sand-catchers at each of the sewage interceptors to prevent part of the detritus from entering the intercepting sewer, and another sand-catcher on the intercepting sewer east of the river, where the sewer invert is above the back-water and

Mr. Griggs. the sewer itself has a shallow cover, is being considered, but whatever may be done in these respects the writer believes that some mechanical device for cleaning and keeping clean the existing sand-catcher near the main sewage pumping station will be found desirable and necessary.

Mr. Winslow. C-E. A. WINSLOW, ESQ.* (by letter).—All who are interested in sanitary matters must feel indebted to Mr. Gregory for this comprehensive and detailed account of the important developments in water and sewage practice which have been worked out at Columbus, Ohio. Profitable discussion is suggested by many points in connection with both of the new plants, but the influence of the Columbus experiments and designs on the history of sewage purification is the particular phase of the subject which appeals most strongly to the writer.

Progress in sanitary engineering in the United States has been marked by half a dozen striking and epoch-making investigations. In water purification, the construction of the Lawrence filter, in 1893, the Louisville experiments in 1898, and the disinfection of the Jersey City water supply in 1908, form notable landmarks. Modern sewage purification began at the Lawrence Experiment Station of the Massachusetts State Board of Health in 1890. Then for fifteen years the lead was taken by English engineers; and the report by George A. Johnson, Assoc. M. Am. Soc. C. E., on the Columbus experiments in 1905 marks the next really important and fundamental advance in American practice.

The Columbus experiments, followed by the construction and operation of the 20 000 000-gal. plant, demonstrated that the trickling or sprinkling filter could be operated successfully under American conditions, and in a moderately severe Northern climate. Since 1905 the opinion has rapidly gained ground that, under ordinary conditions, and with the possible exception of small cities situated where sand is easily available, the trickling process is the most economical of all methods of sewage purification. The plants at Washington and Reading, Pa., are obviously modeled after the Columbus studies; and experimental work at Boston, Baltimore, Philadelphia, and Chicago, tends in the same direction.

There are minor points in the design of trickling filters, which remain to be worked out, of which the method of distribution is undoubtedly of the first importance. In regard to this the writer is inclined to believe that the Columbus model will be modified considerably in future plants. The discharge of sewage from fixed sprinkler nozzles with large circular orifices tends to be defective, for two reasons: The quantity of sewage discharged on the wetted area from such a nozzle is too large for efficient purification; and the distribu-

* Biologist-in-Charge, Sanitary Research Laboratory and Sewage Experiment Station, Massachusetts Institute of Technology.

Mr. Winslow.

tion is notably uneven. At Columbus the first objection has been met by intermittent operation (the bed being dosed at first for 6-hour periods and finally for periods of only 15 min.), and by reducing the diameters of the nozzle orifices on six of the filters from $\frac{9}{16}$ in. to between $\frac{15}{32}$ and $\frac{7}{16}$ in. The second difficulty, of uneven distribution within the wetted area, has been met by operating the nozzles under three different heads, during successive 15-min. periods. If a varying head must be used, however, it seems more reasonable to adopt a nozzle like that designed by W. Gavin Taylor, M. Am. Soc. C. E., to discharge in a sheet rather than over a ring; and Mr. Taylor's nozzle has the further advantage of covering approximately a square and avoiding waste area or the overlapping of circles. If varying head is not to be used, the Technology gravity distributor, in which the sewage is discharged downward on a disc from which it splashes up and out, gives a more even distribution than any fixed device, except nozzles like those used at Birmingham, which have the defect of very small openings subject to serious clogging.

There is no doubt, on the whole, that the trickling filter furnishes a cheap and satisfactory method of securing organic stability. It is an ideal oxidizing machine. The problem of suspended solids, however, it does not solve; and this remains the most serious problem in sewage disposal. The analytical data for the operation of the Columbus plant for 1909, given by Mr. C. B. Hoover, are the basis for the figures in Table 20, which indicate the extent of this problem in a striking manner. The figures for the mean daily flow through

TABLE 20.—SUSPENDED SOLIDS AT COLUMBUS, 1909.

| | Mean daily flow, in millions of gallons. | SUSPENDED MATTER REMOVED (INFLUENT MINUS EFFLUENT). | | |
|---|---|---|---|---|
| | | Parts per million. | Pounds per day. | Tons per year. |
| Septic tank | 11.1 | 118 | 10 892 | 1 777 |
| Sedimentation tanks | 5.8 | 43 | 2 072 | 338 |

the sedimentation tanks have been calculated from the data relating to the percentages of the time these tanks were in service, assuming that the periods were representative ones. It appears from Table 20 that 2 115 tons of dry solid material are annually removed from the Columbus sewage, amounting to about $\frac{1}{2}$ ton per 1 000 000 gal. A part of the 1 777 tons deposited in the septic tanks will of course be liquefied, but probably not more than half. Mr. Hoover's figures indicate that four of the tanks were cleaned twice during the year, and the other two four times. At present Columbus is fortunate in being able to

Mr. Winslow.

discharge its sludge into the Scioto River at periods of high water. For cities not so well situated this question of sludge disposal remains a very real one.

There are two main lines along which the solution of this problem may perhaps be sought profitably. The first is the perfection of the septic tank, or some other form of biolytic chamber, so that a larger proportion of the sedimented solids may be eliminated by microbic digestion. The writer has become convinced that the principal factor which prevents more complete solution of suspended solids is the over-septic condition of the sludge due to the accumulation of waste products of bacterial life. If this be the case, tanks built like the Hampton and Emscher tanks, in such a fashion as to separate the sludge from the flowing sewage, keeping the sewage fresh and the sludge as stagnant as possible, are designed on a diametrically wrong principle, as far as the sludge solution is concerned. At the new experiment station of the Massachusetts Institute of Technology, the reverse principle has been applied. A septic tank has been constructed on the Dortmund pattern, the influent entering near the bottom and being skimmed off at the top, so that the sludge is constantly washed and kept from an over-septic condition by the incoming sewage. No data as to sludge digestion are as yet available, for the tank, thus far, has been operated (8 months) without the necessity for cleaning; but the effluent is of excellent character.

The other possible avenue of approach to the sludge problem lies along the line of utilization. The history of sewage purification is one long story of disappointment as to the extraction of any useful by-products; yet the failures of the past cannot limit the possibilities of the future. Reports of the results already achieved in England and Germany by the reawakening of efforts along this line are not very convincing. It is possible, however, that some mechanical improvement may at any time bring the utilization of concentrated sludge—particularly where manufactural wastes are present—within the range of practical consideration.

Messrs. Scott and McDowell.

MESSRS. R. D. SCOTT* AND R. F. MCDOWELL† (by letter).—During recent years, and prior to 1909, the Scioto River, at and below Columbus, has been unsightly in appearance and foul smelling during low-water stages. This is what might have been expected, as at least one-half of the flow at such times was sewage.

As observed in January, 1909, the river bed was covered with a deposit of sludge from 1 to 12 in. deep. The appearance of the surface of the stream was marred by floating masses of sludge, and odor from the river was noticeable for a distance of at least 100 ft. from the banks.

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†Civ. Engr., Ohio State University.

Messrs. Scott and McDowell.

During the summer and fall of 1909, about one-half of the raw sewage from that part of the city east of the river, was discharged directly into the river, owing to the cleaning of the intercepting sewer. For this reason, there was but little improvement over previous conditions during this time. Consequently, it will be impossible to show the effect of the purification of the sewage on the sanitary condition of the river under low-water, warm-weather conditions, until after the summer of 1910.

The composition of the water of the Scioto and Olentangy Rivers above the city, is indicated by the analyses given in Table 21.

TABLE 21.

| | Scioto River, at storage dam. | Olentangy River, about 2 miles above the city. |
|---|---|---|
| Date | April 23d, 1909. | October 5th, 1909. |
| River elevation, in feet, above low water | 2.8 | 0.0 |
| Temperature of water, in degrees Fahrenheit | ..... | 57.0 |
| **Analytical Results, in Parts per Million.** | | |
| Suspended matter | 15.0 | 7.0 |
| Oxygen consumed | 7.0 | 5.0 |
| Nitrites | 0.013 | Trace. |
| Nitrates | 3.3 | 0.1 |
| Organic nitrogen | ..... | 0.3 |
| Free ammonia | 0.10 | 0.03 |
| Chlorine | 4.5 | 10.0 |
| Dissolved oxygen | 9.3 | 9.8 |
| Bacteria (whole numbers) | 6 000 | 80 |

The sanitary condition of the Scioto above the sewage works and at various stages during 1909, is shown by results of analyses of samples taken ½ mile above the outfall. These results are recorded in Table 22.

TABLE 22.

| Date. | River stage, in feet above low water. | Analytical Results, in Parts per Million. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Suspended matter. | Oxygen consumed. | Nitrogen as: | | | | Chlorine. | Dissolved oxygen. | Bacteria, in millions per cubic centimeter. |
| | | | | Nitrites. | Nitrates. | Organic nitrogen. | Free ammonia. | | | |
| Jan. 1, 1909 | 0.0 | 11 | 12 | ..... | ..... | ..... | ..... | 25 | 0.0 | 0.098 |
| Jan. 3, 1909 | 0.0 | 18 | 9 | ..... | ..... | ..... | ..... | 27 | 0.5 | 0.220 |
| Jan. 23, 1909 | 0.9 | 105 | 16 | 0.45 | 1.0 | ..... | ..... | 27 | 4.7 | 0.700 |
| Feb. 6, 1909 | 1.1 | 74 | 23 | 0.50 | 0.7 | ..... | ..... | 18 | 7.2 | 0.400 |
| Feb. 16, 1909 | 7.0 | 350 | 16 | ..... | ..... | ..... | ..... | 5 | 12.6 | 0.075 |
| Mar. 5, 1909 | 3.2 | 174 | 11 | 1.14 | 5.8 | ..... | ..... | 4.5 | 12.2 | 0.008 |
| Apr. 5, 1909 | 1.4 | 28 | 8 | 0.01 | 3.9 | ..... | ..... | 7.5 | 10.6 | 0.026 |
| Apr. 16, 1909 | 1.8 | 32 | 8 | 0.014 | 4.0 | ..... | ..... | 6.5 | 9.8 | 0.017 |
| Apr. 28, 1909 | 1.2 | 36 | 9 | 0.012 | 3.0 | ..... | ..... | 9.0 | 10.2 | 0.024 |
| Sept. 20, 1909 | 0.0 | 25 | 14 | Trace | 0.2 | 2.3 | 4.3 | ..... | 0.0 | 2.350 |
| Sept. 21, 1909 | 0.0 | 21 | 14 | Trace | 0.0 | 2.2 | 4.6 | 39.0 | 0.0 | 1.980 |
| Sept. 29, 1909 | 0.0 | 26 | 14 | Trace | 0.1 | 2.5 | 5.9 | 47.9 | 0.0 | 0.489 |

Messrs. Scott and McDowell.

The bad condition of the river, prior to February, 1909, as shown by the results recorded in Table 22, is explained by the fact that for the previous six months, the river had been at an extreme low-water stage, during about one-half of which time (before the sewage works began to operate) all the raw sewage was discharged into it. Between the beginning of this long-continued, low-water stage of the river and the starting of the sewage works, there had been no floods to scour out the river bed and free it of deposited and decomposing sludge. From June 1st, 1909, to the beginning of freezing weather, the intercepting sewer was being cleaned and raw sewage was discharged into the river. This latter fact accounts for its bad condition, as indicated by the September analyses.

The effluent from the sewage works is discharged at the west bank of the river and in a short distance becomes thoroughly mixed with the whole flow of the stream. This is shown by Table 23.

TABLE 23.—RESULTS OF DETERMINATIONS OF CHLORINE, IN PARTS PER MILLION, IN SAMPLES OF RIVER WATER, SHOWING THE MIXING OF THE EFFLUENT WITH THE WATER.

When River Elevation was 1.8 Ft. Above Low Water.*

| | Source of Sample. | | | |
|---|---|---|---|---|
| | West bank. | West center. | East center. | East bank. |
| 100 ft. below outfall..... | 26.0 | 25.5 | 4.0 | 4.5 |
| ¼ mile " " ..... | 12.0 | 7.0 | 5.0 | 5.0 |
| ½ " " " ..... | 11.5 | 6.5 | 4.0 | 5.5 |
| ¾ " " " ..... | 10.5 | 6.5 | 6.0 | 5.0 |
| 1.0 mile " " ..... | 7.5 | 7.0 | 7.0 | 5.5 |
| 1¼ " " " ..... | 6.5 | 4.5 | 6.0 | 4.5 |

When River Elevation was 2.4 Ft. Above Low Water.†

| | | | | |
|---|---|---|---|---|
| 100 ft. below outfall..... | 18.0 | 20.0 | 9.0 | 5.0 |
| ¼ mile " " ..... | 10.0 | 5.0 | 8.0 | 5.0 |
| ½ " " " ..... | 5.0 | 8.0 | 10.0 | 5.0 |
| ¾ " " " ..... | 5.0 | 6.0 | 5.0 | 5.0 |
| 1.0 mile " " ..... | 6.0 | 7.0 | 7.0 | 6.0 |
| 1¼ " " " ..... | 6.0 | 6.0 | 5.0 | .... |

* Chlorine value for effluent at this time was 59 parts.
† Chlorine value for effluent at this time was 56 parts.

As stated, there has been as yet no favorable opportunity to study the Scioto under warm-weather, low-water conditions, but from March 5th to April 28th, 1909, a study of its sanitary condition was made. At this time only purified sewage was being discharged into the river. Samples were taken immediately above the plant and at several points below it. The results of the analyses of these samples are recorded in Table 24. The river was from 1.4 to 2.6 ft. above the low-water stage at this time.

Messrs. Scott and McDowell.

TABLE 24.

| Sample No. | Analytical Results, in Parts per Million. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Suspended matter. | Oxygen consumed. | Nitrogen as: | | | Chlorine. | Dissolved oxygen. | Bacteria, in millions per cubic centimeter. |
| | | | Nitrites. | Nitrates. | Free ammonia. | | | |
| 1 | 32 | 8 | 0.012 | 3.6 | 0.21 | 7.7 | 10.2 | 0.0224 |
| 2 | 26 | 7 | 0.026 | 3.2 | 0.32 | 10.7 | 8.7 | 0.0345 |
| 3 | 29 | 9.5 | 0.037 | 3.2 | 0.40 | 10.7 | 8.6 | 0.0415 |
| 4 | 34 | 7 | 0.044 | 2.5 | 0.20 | 11.0 | 8.2 | 0.0135 |
| 5 | 23 | 7 | 0.035 | 3.0 | 0.11 | 9.5 | 8.6 | 0.0342 |
| 6 | 32 | 7 | 0.046 | 2.5 | 0.16 | 7.8 | 8.6 | 0.0092 |

Sample No. 1 = Average of four samples taken 0.5 miles above the outfall.
" No. 2 = " " " " " 3.9 " below " "
" No. 3 = " " three " " 6.75 " " " "
" No. 4 = " " two " " 11.3 " " " "
" No. 5 = " " one " " 17.5 " " " "
" No. 6 = " " three " " 25.0 " " " "

On October 6th, 1909, some analyses were made which show the self-purifying ability of the Scioto when low-water conditions prevail. These samples were taken during the time when the intercepting sewer was being cleaned, and when from 30 to 50% of the total flow of the raw sewage of the city was being discharged into the river. These results are recorded in Table 25.

TABLE 25.

| River. | Distance, in miles, from sewage works. | Temperature, in degrees, Fahrenheit. | Suspended matter. | Oxygen consumed. | Nitrogen as: | | | | Chlorine. | Dissolved oxygen. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Nitrites. | Nitrates. | Organic nitrogen. | Free ammonia. | | |
| Olentangy.... | 11.5 above | 57 | 7 | 5 | Trace | 0.11 | 0.34 | 0.03 | 10 | 9.8 |
| " .... | 6.3 " | 57 | .... | 6 | ..... | .... | .... | .... | 12 | 6.0 |
| " .... | 5.2 " | 57 | .... | 8 | ..... | .... | .... | .... | 18.5 | 4.4 |
| Scioto ..... | 4.0 " | 59 | ... | 17 | ..... | ... | ... | ... | 36.5 | 0.0 |
| " ..... | 0.5 " | ..... | 21 | 17 | Trace | 0.16 | 2.10 | 4.10 | 49.0 | 0.0 |
| " ..... | 3.9 below | 59 | 10.5 | 10.5 | Trace | 0.15 | 3.30 | 5.50 | 45.0 | 0.3 |
| " ..... | 6.75 " | 63 | 4.5 | 9.0 | 0.085 | 0.35 | 2.6 | 4.9 | 43.0 | 5.8 |

The self-purification of streams has often been noted, but the improvement here is unusual for so short a distance. It is partly explained by the aerating effect of the many riffles in the first 6 miles below the plant.

A comparison of the composition of the river water just above the plant, at a time when the river was receiving about one-third of the raw sewage of the city, with the effluent from the plant, might be of

Messrs. Scott and McDowell.

interest. The results given in Table 26 are averages of samples, of both river water and effluent, taken on September 20th, 21st, and 29th, 1909. The river was at an extreme low-water stage at this time.

TABLE 26.

| | Analytical Results, in Parts per Million. | |
|---|---|---|
| | River water. | Effluent from sewage works. |
| Suspended matter | 24.0 | 26.0 |
| Oxygen consumed | 14.0 | 15.0 |
| Nitrites and nitrates | 0.1 | 3.7 |
| Chlorine | 43.0 | 70.0 |
| Dissolved oxygen | 0.0 | 4.3 |
| Bacteria (millions per cubic centimeter) | 1.60 | 1.63 |
| Days required to decolorize 1 cu. cm. of a 0.1% solution of methylene blue per 250 cu. cm. of sample when incubated at 37° cent | 0.23 | 4.5 |

It is evident that in the future a very decided betterment of the sanitary condition of the river during warm-weather, low-water times may be expected. The effluent from the sewage works, itself non-putrescible 75% of the time, will be diluted at such times with approximately an equal volume of only slightly polluted river water.

Mr. Wagner.

Samuel Tobias Wagner, M. Am. Soc. C. E. (by letter).—It is unique, in the presentation of papers to this Society, that there should be combined in one paper the description of a plant for the purification of the water of a municipality for domestic purposes and, at the same time, a description of a method for the treatment of its sewage. This paper is specially interesting on account of the fact that it treats both subjects comprehensively, and describes not only the construction with great detail, but also the operation for a period sufficient to show the results which may be expected when everything has got a bearing and is running in a regular manner. An item of great value is the detailed supervision of the costs. Such detail is unusual in work of this magnitude, as it is difficult to separate it without much painstaking, and the author is to be congratulated not only for its admirable arrangement but also for the presentation of the whole subject in such a logical and complete manner. It is the duty of every engineer to emulate such an example, and to prepare and present papers on the work under his charge as promptly after completion as has been done in this case.

Under the head of "Pumping Station," the author alludes to the fact that the ordinary cut stone used in the trimming of buildings of this class was replaced with concrete constructed in special moulds and with carefully finished surfaces. Architectural treatment of this

kind is of special interest at this time when concrete is being used to so great an extent, and the writer would like to see a photograph of at least a portion of this building, showing the appearance of the parts thus treated as well as one or two details. As gleaned from the description, the general effect must be very satisfactory. Mr. Wagner.

The problem of purifying a water of the character described, by softening and then by mechanical filtration, is unusual and very interesting. Apparently, no preliminary investigations on an experimental scale were made to determine the best methods for its treatment. If no such experiments were made, great credit is to be given for the design of the details of the plant, as the combinations and rapid variations in the amounts of "total hardness" and "turbidity," given in the tables covering the period of operation, are indicative of the care taken to secure satisfactory effluents. The writer does not recall any published data dealing with a water of such a character. The tables relating to the operation of the filters from January to August, 1909, show that the results are steadily improving as experience with the water increases, and any data of later operations which may be given by those in charge of the plant will be of great interest as indicating the effect of this treatment on the water.

It is not surprising that detailed experiments were made on the sewage to be treated, not only because of the fact that it was desirable to obtain all the data possible as to its peculiarities before proceeding too far with the design, but also because at the time the plant was projected the general question of sewage treatment in the United States on such a large scale was in its infancy. Great credit is due to the city authorities for permission to spend the money necessary for these experiments, and it is now possible for them to see the wisdom of their action. The problem of sewage treatment of large cities in the United States is undoubtedly one of the most vital sanitary questions, and, in the very near future, it is certain that many municipalities will be compelled to spend enormous sums of money for such improvements. Such a complete description of this work at the present time, therefore, is most opportune and valuable.

From an examination of the tables of costs, it would appear that Columbus has now completed a large municipal work of excellent design and at a very reasonable cost.

J. CORBETT, ESQ.* (by letter).—This work seems to be remarkably bold and complete to have been carried out in so short a time, and there is no doubt that it will prove eminently beneficial to Columbus. Mr. Corbett.

The Scioto River Storage Dam is of such ample section that it cannot, in all human probability, cause any risk to the great city below it.

* Borough Engr., Salford, England.

Mr. Corbett.

The water-softening and filtering arrangements seem to be very efficient in actual working; but, without the evidence given in Table 12, the writer would have thought it impossible to work the fine sand filters at the rate of 120 000 000 gal. per acre per day, as stated. This rate is far greater than any of which he has record, except for coarse-sand preliminary filters. The cleansing of the filter by water and air seems to be very simply and effectively arranged, and no doubt accounts for the wonderful rate of working.

Turning to "The Improved Sewage Works," some of the best features of the works at Birmingham and at Salford seem to have been selected, but it may yet be found expedient to add some sort of straining filter between the septic tanks and the bacteria beds. Experience at Salford has shown that these beds gradually become choked with the solid matters passing on to them, even when, as at Birmingham and Columbus, the medium averages more than 1 in. in diameter. There is space enough, however, for such an addition, if found requisite.

The hexagon plan for the bacterial filters, with its central gate-house, etc., seems to be an excellent arrangement, but no mention is made of provision for a fall from the center to the circumference, in order to equalize the pressure on the spray jets. The writer has found a fall of 1 in 250 for a whole structure very efficient.

The spray jets used at Columbus are of the type preferred by the writer for septic effluent, because having only one hole, they are less likely to choke; their fault of throwing the drops in a ring, however, needs the corrective proposed, that is, an automatic variation of the head. The writer used this type on experimental filters from 1893 to 1898, but, on the permanent beds, substituted the well-known two-hole jets, and, later, some with six internal holes. These give no trouble with the sewage liquor which has passed through the coarse-sand roughing filters.

The normal rate of working the filters at Columbus, 2 000 000 gal. per acre per day, is the same as that used at Salford, with $\frac{1}{4}$ in. to 1 in. medium, with double this rate during wet weather. The writer is not aware of any coarse-grained filters, like those at Columbus, which treat English sewage efficiently at this rate; but no doubt this rate may be used in treating the more dilute sewage at Columbus.

In a few years the filter beds will probably become clogged to such an extent that the whole medium will require to be dug out and washed; but as there is an ample water supply, this may not be a very costly renovation.

As to the aeration of the filter beds, the writer is of the opinion, though he cannot quote any actual facts in its support, that the beds would be improved by some ample air pipes carried down to the collecting channels, so as to provide for a current vertically through the medium.

Mr. Corbett.

It is to be hoped that there may soon be an opportunity to abandon the disposal of the sludge into the river during freshets. It seems to imply either a very irregular cleansing of the settling basins and septic tanks, or a certain laxity in the definition of freshets in the river.

Looking to the whole work of water supply and sewage disposal, the writer heartily congratulates the author on its evident efficiency, and on the considerable ingenuity and originality shown in many of its details.

Mr. Copeland.

W. R. COPELAND, ASSOC. AM. SOC. C. E. (by letter).—Mr. Gregory refers to the fact that the underlying rock of the Scioto River water-shed is limestone. It may be described more correctly as a dolomite, or a mixture of lime and magnesium carbonates, combined with sulphates and chlorides of the same bases. These salts make the water hard, and therefore the water-softening process is one of the most important features of the Columbus water purification works.

In softening the water "quick" or "fresh-burned" lime is used to remove the carbonates and magnesium salts, and "soda ash" or "carbonate" of soda to remove the sulphates and chlorides. Lime has been used for years to remove carbonates from municipal water supplies, but Columbus is the first city to undertake to remove the sulphates and chlorides by soda ash on a scale as large as 30 000 000 gal. in 24 hours. Moreover, the presence of magnesium makes the problem more complicated than in many purification works, and its removal has not ordinarily been attempted in city water-softening plants heretofore.

The results obtained at Columbus demonstrate that the magnesium, the sulphates, and the carbonates can be removed without difficulty at all seasons of the year, provided the softening chemicals are applied properly and the operation of the plant is watched by trained men.

As the bed-rock of the water-shed is dolomite, the ground-waters or waters which work into the river during dry seasons are heavily charged with salts which make the water hard. In wet seasons the conditions are reversed, and the river contains large volumes of soft surface water, carrying mud scoured from the cultivated fields, bacteria washed from sewers and barn yards or fields, and vegetable coloring matter from woods and swamps. It is evident, therefore, that the river water changes in character markedly, and these changes take place more rapidly, perhaps, than in any other municipal plant where water softening combined with purification is conducted on such a large scale.

These conditions arise partly from the fact that a current flows through the storage reservoir continuously, and so rapidly in a flood that the total volume may be displaced two or three times in 24 hours.

Mr. Copeland.

In other large cities the water supplies are equipped with great settling basins which store the raw water for several hours or even days if muddy, and equalize the fluctuations, but the Columbus plant must take whatever is flowing in the river—hard or soft, and clear or turbid water.

Through the courtesy of the superintendents of the plants at Cincinnati and New Orleans, data obtained in those cities during 1909, are presented in Table 27 for comparison with those from Columbus.

TABLE 27.—COMPARATIVE DATA AT CINCINNATI, NEW ORLEANS, AND COLUMBUS.

All in parts per million.

CINCINNATI—1909.

| | River Water. | | | Settled (Coagulated) Water. | | | Filtered Water. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Avg. | Max. | Min. | Avg. | Max. | Min. | Avg. |
| Total alkalinity | 95 | 21 | 46.2 | 78 | 30 | 51.1 | 74 | 27 | 49 |
| Incrustants | 79 | 7 | 28.2 | ..... | ..... | ..... | 72 | 8 | 36.7 |
| Turbidity | 2 000 | 15 | 225 | 68 | 12 | 23 | 0 | 0 | 0 |
| Number of bacteria per cubic centimeter | 132 000 | 80 | 9 300 | 11 500 | 10 | 475 | 800 | 0 | 75 |

NEW ORLEANS—1909.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Total alkalinity | 180 | 60 | 95 | 115 | 29 | 49 | 84 | 27 | 46 |
| Incrustants | 160 | 10 | 25 | ..... | ..... | ..... | ..... | ..... | 33 |
| Turbidity | 2 500 | 50 | 600 | 250 | 2 | 38 | 3 | 0 | 0 |
| Number of bacteria per cubic centimeter | 10 000 | 500 | 2 000 | 1 100 | 20 | 200 | 400 | 2 | 26 |

COLUMBUS—OCTOBER 1ST, 1908, TO SEPTEMBER 31ST, 1909.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Total alkalinity | 250 | 50 | 162 | 106 | 23 | 54 | 98 | 3 | 43 |
| Incrustants | 287 | 11 | 108 | 118 | 12 | 51 | 87 | 11 | 50 |
| Turbidity | 1 500 | 4 | 76 | 104 | 0 | 13 | 4 | 0 | 0 |
| Number of bacteria per cubic centimeter | 125 000 | 25 | 7 100 | 50 000 | 0 | 680 | 5 850 | 0 | 145 |

Recognizing the fact that conditions change in the river water through a wide range, the designing engineers built many devices at Columbus for making the application of chemicals to the water elastic. Even so, however, experience has shown that the adjustments in the regulating apparatus were not sufficiently extensive to cope with the variations in composition of the river water. In addition to this, the lime varies in composition, and often carries from 10 to 20% of "foreign" matter, consisting of "unburned" rock, cinders, bricks, etc. All such stuff had to be carried away in buckets at first, as the drain pipes leading from the slaking and solution tanks were

too small, but since they have been replaced by 3- and 4-in. drain pipes it is an easy matter to wash them out to the river. Mr. Copeland.

Fine-mesh screens of large area have also been placed over the outlet pipes leading to the chemical feed regulators, and extra stirring arms have been attached to the agitators in the solution tanks in order to keep the suspended matter from settling.

Designing engineers will do well to note that wherever sludge finds a chance to lodge, as in elbows, valves, measuring devices, etc., sediment accumulates, rapidly shutting off the flow, and interfering with the application of chemicals. Such deposits cause frequent and annoying interruptions of the lime feed at Columbus, requiring a laborer to flush them out at frequent intervals.

The soda and coagulant solutions do not carry débris in such large quantities nor of the same character, but, as these chemicals are sometimes shipped in jute or burlap sacks, the fine hairs rubbing from the cloth form mats over the screens. To correct these conditions, removable screens have been installed at the outlets of the dissolving tanks, and "constant head" boxes in front of the orifices.

In addition to the interruptions of flow caused by these "foreign" impurities, the lime, soda, and sulphate of iron solutions form calcareous, crystalline, and scaly deposits which choke the delivery pipes in a short time unless flushed frequently by jets of water under pressure. For example the 8-in. cast-iron pipes, which deliver a mixture of lime liquor and raw water at four points in the saturators, become filled, in a 2-weeks run, with granular accretions of calcium carbonate to such an extent that one could not run a 2-in. pipe through the opening left. The bore of the "lead-lined" coagulant pipe in the gate-house is reduced by flakes of iron rust from 3 in. to $\frac{1}{4}$ in. in many places. This pipe is laid for part of the way in concrete and is submerged in water during the ordinary course of work, thus making these accumulations in the coagulant lines especially serious, because the piping is inaccessible for cleaning.

All such important apparatus should be placed in open areas which are easy of access, and should be provided with plenty of flange unions so that the pipes can be taken apart for cleaning.

The coagulant solutions have eaten the steel pipes wherever the lead lining is broken—as at joints between valves and fittings—and it seems as though it would be advantageous to make long stretches of coagulant lines of cast iron.

Lime solutions are not corrosive in themselves, but the suspended particles carried by the milk of lime, flowing through the "chemical feed regulator," cuts the edges of the orifice plates, screens, and valve seats. The soda solution attacks concrete, dissolving out the calcium sulphate and leaving the sand and gravel, which makes the walls of the concrete tanks rough.

Mr. Copeland.

The acid carried by the sulphate of iron and alumina solutions dissolves the carbonates out of the concrete tanks, eats the iron pins out of the valves, and, in fact, is destructive to almost all metals except lead, though brass pipe stands well.

After passing the chemical feed regulator, the lime liquor mixes with 60% of raw water and enters the saturators. According to the original design, from 15 to 25% of raw water was to have been diverted through the saturators to make clear saturated lime-water containing 60 grains of CaO per gallon. Soon after starting the plant, however, this method of procedure was changed because the lime liquor rose in restricted areas and the effluent from the saturators rarely carried more than 45% of CaO.

Finding that the original plan was not efficient, additional paddles were attached to the rotary stirring shafts, and larger volumes of raw water were forced into the saturators. By this procedure more magnesium is precipitated, because larger volumes of raw water come into contact with the lime while it is still caustic—a condition which is necessary for converting the soluble bicarbonate into the insoluble hydrate. This hydrate, together with some precipitated carbonate of lime, forms a sediment in the liquor flowing from the saturators. The particles of suspended matter serve as nuclei on which the water-softening precipitates, which develop in the reaction chambers, may collect. The sludge formed by the precipitates, together with the coagulated mud, collects for the most part in the first sections of Settling Basins 1 and 2. This deposit has a soft jelly-like consistency, forming, in 3 or 4 weeks, a mass from 12 to 15 ft. deep near the inlet ends of the eastern compartments of Basins 1 and 2. The depth of the sludge falls off rapidly to 4 or 5 ft. at the outlet ends of these basins, and sediment to a depth of only about 3 or 4 ft. collects in the other basins during the year. When a basin is to be cleaned, the inlet and outlet water-gates are closed, and the valves on the drains in the floor of the basin are opened, allowing the sludge to escape to the river. Most of the sludge will run out in this manner, and what remains is flushed out readily with a 2½-in. fire stream. By using hose, six men clean a basin in from 3 to 4 hours.

Attention is called to the fact that the settling basins remove most of the chemical precipitates, mud, and bacteria. In fact, it is necessary that from 80 to 90% of such materials should be taken out there in order to obtain a pure clear effluent from the plant. In order to secure this result, provision was made originally for applying coagulant at the entrance to each or any set of basins, at the outlet of the last basins, and in the settled-water channel on the way to the filters; but experience has shown that better efficiency is obtained by adding most of the coagulant to the raw water as it enters the plant, and a small additional dose to the settled water as it passes to the

Mr. Copeland.

filters. There are two reasons for this. In the first place, by adding coagulant to the raw water at the inlet the whole body of water becomes charged and is in such a condition that when the caustic lime strikes it the coagulant precipitates in large flocks.

Unfortunately, however, certain species of bacteria grow, at some seasons, in the sludge deposited in the mixing chambers, conduits, and settling basins. Moreover, the water-softening reactions require several hours to become complete, and, as the precipitate of calcium carbonate is very fine, a secondary turbidity sometimes develops in the settling basins.

These bacterial growths and the turbidity resulting from the water-softening reactions constitute a second reason for adding a dose of coagulant at the outlet of the settling basins to form a mat on the surface of the filters for removing the last traces of suspended matter and bacteria. When the sediment is coarse and heavy—for instance, in the early stages of a flood—a comparatively small amount of coagulant will clarify the water, but, toward the end of the flood, when the particles of sediment become fine and the coloring matter from the swamps and fields increases, coagulants do not react with their usual efficiency.

It becomes necessary at such times to add a slight excess of lime so that the effluent from the mixing tanks shall have from 10 to 15 parts per million of caustic alkalinity. Laboratory experiments indicate that this excess of caustic is required to replace the alkaline bicarbonate of lime removed by the water-softening process and to coagulate the finely-divided particles of suspended matter which remain. As there are only a few days in the year when lime is not required for softening, it would not be possible to cut the lime out for any considerable number of days in succession. Therefore, at Columbus it is not possible to depend on the bicarbonates, which are carried naturally in the water, to precipitate the coagulant. The treated water always carries a considerable quantity of monocarbonate of lime, but this alkaline salt does not seem to react with sulphate of iron or alumina in the same manner as bicarbonate or caustic lime.

A glance at the tables in the paper will show that large quantities of coagulant were used occasionally. These applications were made in order to remove the bacteria which grew in the sludge, and as the treatment did not prove to be wholly satisfactory, hypochlorite of lime is being used at present to increase the bacterial efficiency and for the purpose of economy.

When the settled water applied to the filters has a turbidity of less than 25 parts per million and contains a little coagulant, the sand beds remove the suspended matter without difficulty. During the early part of 1909, however, the gravel underdrains were deranged, and the sand grains became coated to some extent with deposits of

Mr. Copeland.

lime and iron, making it necessary to coagulate the turbidity in the settled water with extra alum.

From August to December, 1908, compressed air was applied to the beds of sand during the process of washing, but as the current of wash-water applied seems to clean the beds sufficiently, the treatment with compressed air has been discontinued.

The designing engineers expected that the filters would be washed with a current of water having a maximum upward velocity of 10 in. per min. The actual rate does not exceed 6 or 8 in., however, and the velocity is as great as can be used without lifting the sand into the gutters. It is possible, also, that screens would have to be placed over the under-drains, or deeper layers of large-sized stone laid on top of the strainers to prevent the gravel from being dislodged, if the current of wash-water should be applied at a higher rate.

The writer desires to add a word of praise for Mr. Gregory and the engineers who assisted him in designing and building the plant. They had very little knowledge of the character of the Scioto River water to guide them, and the data in regard to the best method of treatment for softening the water were gained from a series of laboratory tests carried out with small volumes of water for a period of only 2 or 3 months.

The plant has handled the water successfully, the typhoid fever rate has been reduced, the people have abandonded their cisterns, and the water gives general satisfaction for boiler purposes.

On account of the "flashy" character of the river water, however, the plant requires constant watching, and for that reason the bills for superintendence and labor have been high.

Mr. Sperry.

W. A. SPERRY, ESQ.* (by letter).—It may not be amiss to mention the problem confronting those having the water purification works in charge in finding a supply of lime of sufficient purity and within a distance such that the freight charges would not prohibit its use.

Something of the importance of this problem may be realized when it is remembered that during a period of 13 months the average daily consumption of lime was 9.2 tons; the average total hardness of the Scioto River for the same period was 270 parts per million, 60% of which required lime treatment; the magnesium averaged 23.4 parts per million, and required an extra lime treatment.

Experience gained at this plant has shown that those limes which contain less than 1% of magnesium, and 90% or more of calcium oxide (CaO) are most economical and give the most efficient and reliable results, and that local limes are sufficiently high in silica, alumina, iron, and especially in magnesium, to reduce the percentage of available calcium oxide to less than 80. It should be said, further, that it has rarely been possible to obtain limes delivered at the

* Asst. Chemist, Columbus Water Purification Works.

plant with more than 88% of available calcium oxide, the low percentage being chargeable to weather conditions, distance hauled, and the much more rapid loss of available calcium oxide by the fine particles than the larger sizes in a body crushed lime, there being a loss of from 2 to 5% of available calcium oxide from these causes during transit from the point of shipment. Mr. Sperry.

Table 28 shows the average analysis of the limes furnished by different companies, representing limes from Ohio, West Virginia, Maryland, and Pennsylvania.

TABLE 28.—ANALYSES OF LIMES.

| Company. | CaO. | Total CaO. | Total Mg. | Matter not water-soluble. |
|---|---|---|---|---|
| A | 77.4% | 59.42% | 6.18% | 21.6% |
| B | 79.4% | 60.82% | 5.58% | 18.5% |
| C | 82.5% | ..... | ..... | ..... |
| D | 86.6% | 66.12% | 0.64% | 13.4% |
| E | 87.9% | ..... | trace | ..... |
| F | 87.7% | ..... | ..... | ..... |
| G | 88.0% | 66.36% | 1.62% | ..... |

The chief source of loss of calcium oxide is by the absorption of carbonic acid gas from the atmosphere, that is, carbonation, and seems to be due to the three causes just mentioned. One of the specifications under which lime is furnished to the plant calls for a lime crushed to a size not greater than 2½ in. in any dimension. It is received in bulk in tight box cars and is sacked at the plant.

Tables 29 and 30 are of interest as showing the relative loss of available calcium oxide in the various sizes of this crushed lime when separated by standard-mesh sieves. In each case cited in the tables about 100-lb. of the lime representing the "run of the car" was separated by sieves of $\frac{1}{16}$- to 1-in. mesh, each size thus separated being weighed and sampled for chemical analysis.

TABLE 29.

| | | | | |
|---|---|---|---|---|
| Car No. 1 | Lime retained by 1-in. mesh | 6.9% | 86.2% | CaO |
| | " passing 1-in. mesh, retained by ½-in. mesh | 33.8% | 85.6% | " |
| | " " ½-in. " " " ¼-in. " | 19.2% | 84.1% | " |
| | " " ¼-in. " " " ⅛-in. " | 14.3% | 85.1% | " |
| | " " ⅛-in. " " " $\frac{1}{16}$ in. " | 7.3% | 82.5% | " |
| | " " $\frac{1}{16}$-in. " | 18.5% | 82.5% | " |
| | Analysis of average sample | | 85.2% | " |
| Car No. 2 | Lime retained by 1-in. mesh | 7.3% | 85.2% | CaO |
| | " passing 1-in. mesh, retained by ½-in. mesh | 37.8% | 80.7% | " |
| | " " ½-in " " " ¼-in. " | 18.1% | 80.9% | " |
| | " " ¼-in. " " " ⅛-in. " | 10.8% | 80.3% | " |
| | " " ⅛-in. " " " $\frac{1}{16}$-in. " | 5.4% | 79.6% | " |
| | " " $\frac{1}{16}$-in. " | 20.6% | 72.2% | " |
| | Analysis of average sample | | 79.6% | " |

Mr. Sperry.

TABLE 30.

| | Car No. 1. | Car No. 2. |
|---|---|---|
| Percentage of available calcium oxide, in cars as received | 89.1% | 85.5% |
| Percentage of available calcium oxide, in cars at time of making mechanical analysis | 85.2% | 79.8% |
| Number of days elapsing between the receipt of the lime and the mechanical analysis | 4 | 16 |
| Loss of available calcium oxide from standing | 3.9% | 5.7% |
| Variation shown between lime obtained by a 1-in. mesh sieve and that passing a $\frac{1}{16}$-in. mesh sieve | 3.7% | 13.0% |

With respect to the relative extent of loss of CaO due to the absorption of $CO_2$ and hydration of lime in storage, the curves in Fig. 18 are of interest. They are the results of a series of laboratory experiments extending over a period of a month or more. A number of 1-gramme samples of lime, ground to pass a 100-mesh sieve, were exposed to the action of the atmosphere in the lime storehouse in a box covered with a cloth in such a way as to give free access of air but to protect them from dust, etc. One of these samples was analyzed each day, note being taken of all atmospheric conditions as shown. Attention is called to the marked similarity of the lime curves after the seventh day.

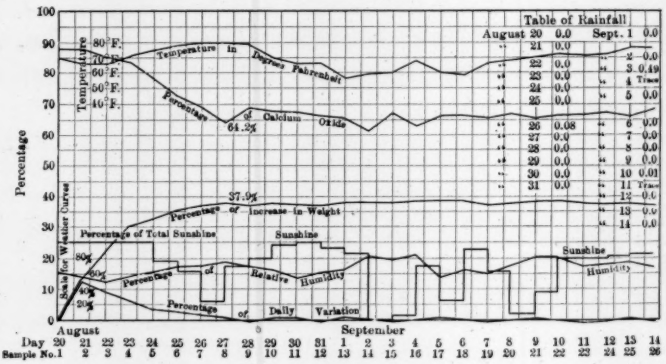


FIG. 18.

At the end of 26 days a series of chemical analyses was made on the samples remaining to determine as nearly as possible the character of the changes that had taken place. It was found:

That the total loss of available calcium oxide amounted to about 19%;

That direct determinations as to the extent of the carbonation by widely differing methods accounted for all but from 1 to 2% of this

loss, and, therefore, indicate that the loss of available calcium oxide is largely due to carbonation; Mr. Sperry.

That the hygroscopic moisture, as determined by the drying test, amounted to from 1.5 to 2.0%;

That, after a time, the loss of available calcium oxide ceases, the lime remaining of the same strength, with slight fluctuations, protected by an outer coating of hydrated and carbonated material;

That the hydration that may take place does not seem to destroy the value of the lime as a water-softening agent; and

That the lime as shipped carries about 1% of unburned stone and about 3% of calcium in a form other than calcium oxide.

J. W. SALE, ESQ.* (by letter).—The Columbus water purification plant started operation in September, 1908. Some months later the city meter inspectors noticed that a number of meters were not registering the flow of water correctly. On examination the meters were found to be clogged with a slimy white deposit which interfered with the rotation of the discs. Later, the trouble subsided to some extent, but seemed to be of sufficient importance to warrant a special investigation. Mr. Sale.

During the summer of 1909 a series of studies was made for the purpose of discovering the extent and nature of the action of the water on metals. At the same time, several proposed remedies were tested. A brief explanation of the water-softening process in use at the plant may help to a clearer understanding of the experiments which follow.

The chemicals used in the softening and purification of the Scioto River water at Columbus are lime, soda ash, and sulphate of alumina or sulphate of iron. The purpose of the lime is to absorb the excess of carbonic acid gas which holds the carbonates of lime and magnesium in solution in the river water and at the same time to remove free carbonic acid gas, if present. When the reaction takes place the newly formed carbonate of lime, together with the carbonate of lime liberated by the removal of the carbonic acid gas, is largely precipitated. It is necessary to make a further addition of lime to convert the magnesium (now in the form of a normal carbonate, which is a more soluble salt than the corresponding carbonate of lime) to the insoluble hydrate. Although, for most purposes, the carbonates of lime and magnesia may be considered insoluble, yet in the excessively dilute condition which is maintained in a water-softening plant they are soluble to the extent of about 40 parts per million.

The soda ash is added to precipitate the other soluble salts of lime and magnesia, namely, the sulphates, chlorides, and nitrates of these metals, as normal carbonates of lime and magnesia. At the same

* Asst. Chemist, Columbus Water Purification Works.

Mr. Sale.

time there are formed, and remain in the water, sodium sulphate, chloride, and nitrate, but the presence of these salts is not objectionable.

The general method of procedure in the experimental work was to expose metals of known weight and surface area to the action of chemically treated water of known composition for definite lengths of time. In this way quantitative results were secured.

The metals chosen were lead, zinc, galvanized iron, and black iron. Zinc pipes are not used, but a zinc coating on a black-iron pipe is in common usage. Other than this, the metals selected are those used for water pipes.

It was learned quickly that sheet lead is unaffected, beyond tarnishing and a slight gain in weight due to surface oxidation. After the film of oxide covered the surface, there was either no increase in weight or the rate of increase was greatly diminished. Lead, therefore, was not included in all the experiments.

In order to learn something of the rate of deposition and to secure sufficient deposit for analysis the following experiment was made: Two glass cells were set up, each having a capacity of 11 liters. These were filled, respectively, with zinc and galvanized-iron plates separated by rubber stoppers. Water having the average composition shown in Table 31, taken from analyses made every 8 hours, was then passed into the bottom of the cells and carried off the surface by a suction arrangement.

TABLE 31.—AVERAGE COMPOSITION OF THE WATER, IN PARTS PER MILLION.

| | | | |
|---|---|---|---|
| Total alkalinity | 46 | Total hardness | 111 |
| Phenol alkalinity | 15 | Turbidity | 0 |
| Caustic alkalinity | 0 | Color | 3 |
| Incrustants | 64 | Magnesium | 15 |

Table 32 shows the details of the experiment.

TABLE 32.

| Metals used. | Extent of surface of metals exposed. | Time of exposure to action of water. | Quantity of water passed over plates. | Amount of deposit recovered. |
|---|---|---|---|---|
| Zinc | 5 000 sq. cm. | 2 weeks | 1 000 gal. | 4.11 grams. |
| Galvanized iron | 5 000 " | 2 " | 1 000 " | 4.06 " |

It will be noticed from the analyses in Table 33 that the deposits recovered from the zinc plates are similar in composition to those from the galvanized-iron plates, with one exception, the deposit on the galvanized iron containing a trace of iron, is absent in the zinc plate deposits.

The analysis of the deposit recovered is given in Table 33. Mr. Sale.

TABLE 33.

| | Zinc plates. | Galvanized-iron plates. |
|---|---|---|
| Zinc | 42.58% | 41.30% |
| Magnesium | 2.14 | 1.63 |
| Calcium | trace | trace |
| Iron | none | trace |
| Sodium | trace | trace |
| $CO_3$ radical | 48.02 | 47.72 |
| $SO_4$ radical | 5.80 | 8.10 |
| | 98.54 | 98.72 |

It appeared that the normal carbonates in the water might be responsible for the action, as the chief constituent in the deposits was zinc carbonate. If such were the case, distilled water having normal carbonates in solution should give deposits on metals. To test this a 50-gal. barrel was steamed out and fitted with a stirring device, which was attached to a small motor. The barrel was filled with distilled water, treated with an excess of freshly precipitated calcium carbonate, which was carried into solution by the carbonic acid gas present. The calculated quantity of lime-water was then added, giving a water with 20 parts of normal carbonate of lime. After settling, the clear water was siphoned through two 500-cu. cm. bottles containing, respectively, zinc and galvanized-iron plates, each having a surface of 75 sq. cm.

The bottles were fitted with two-holed rubber stoppers, the water passing to the bottom of the bottle and out through a bent glass tube with one arm longer than the other. The rate of outflow was controlled by a pinch-cock, and amounted to 1 gal. per hour per bottle. This apparatus was used in many of the succeeding experiments.

Deposits appeared on the surface of each metal, and a relatively large amount was deposited in the bottoms of the bottles.

In this experiment, as well as in succeeding ones of this type, the metals were weighed before and after exposure to the action of the water. The character of the deposit was such, however, that more light was thrown on the relative amount by observation while the bottles were filled with water. After removing the metals and filtering the deposits in the bottom of the bottles, the total deposition on a given metal plate was seldom more than 0.01 gramme, and usually varied from 0.001 to 0.005 gramme.

The same procedure was observed with distilled water treated with normal carbonate of magnesium. To obtain a saturated solution of magnesium carbonate, it was necessary to treat the distilled water with an excess of finely pulverized magnesium carbonate, pass car-

Mr. Sale.

bonic acid gas into the water during agitation, and finally boil the water. Water (50 gal.) treated thus with magnesium carbonate was boiled for ½ hour in liter flasks, and the resulting water, containing 30 parts per million of normal carbonate of magnesium, was passed over metals. Deposits appeared both on the metals and in the bottles, but not in as large quantities as in the case of the water treated with lime carbonate.

To discover whether dissolved oxygen might not contribute to the bad result, an experiment was made as follows: Two carboys, filled with 25 gal. of distilled water, were connected in circuit, and air, previously freed from carbonic acid gas, was bubbled through the water for 24 hours. At the end of this period, the aerated carbon-dioxide-free water was passed over zinc and galvanized-iron plates as usual. The surfaces of both metals were covered with deposit and the bottoms of the bottles contained sediment.

The zinc plates, weighing 30.6754 mg., increased 6 mg. in weight, while the galvanized-iron plates, weighing 27.9458 mg., increased 3.2 mg.

The increase in weight may be accounted for by a combination of the metal with the oxygen carried into the water in the form of air, and with normal carbonates which remained dissolved in the water after the lime and soda treatment.

At this point the action on metals of a softened water containing varying amounts of caustic was taken up, 50 gal. of raw river water being treated with an amount of lime and soda calculated from the analyses to give a water comparable to the filtered water leaving the plant at that time, the difference being in the amount of caustic present in the specially prepared water. Three experiments were made, the caustic present being, respectively, about 5, 15, and 20 parts per million, calculated as carbonate of lime. The same procedure was observed in each experiment, as follows: The quantity of raw water treated was 50 gal., and 60% of this was treated with lime cream of a known strength, in amount sufficient to give the caustic desired in 100% of the water. After agitation for 1 hour in the barrel, the remaining 40% of raw water was added, followed by agitation for 15 min. Sodium carbonate in solution was then introduced into the water followed by thorough mixing for an hour. After complete clarification by settling, the water was siphoned over lead, zinc, galvanized-iron, and black-iron plates, as usual. Side by side, a duplicate apparatus was set up and tap water was passed over similar plates for the same length of time, and in equal amounts. At the end of the experiment the metal plates were removed, dried carefully, and examined for relative amounts of deposit. The weights of the metals were taken before and after exposure to the water. The analyses of the water are given in Table 34.

TABLE 34.

Mr. Sale.

| Experiment No. | | Total alkalinity. | Phenol alkalinity. | Caustic alkalinity. |
|---|---|---|---|---|
| I... | City water | 40 | 14 | 0 |
| | Specially prepared water | 37 | 21 | 5 |
| II.. | City water | 36 | 17 | 0 |
| | Specially prepared water | 43 | 29 | 15 |
| III. | City water | 35 | 16 | 0 |
| | Specially prepared water | 42 | 30 | 18 |

The lead plates in all cases increased slightly in weight, namely, 0.5 to 2.0 mg., on plates weighing about 15 grammes, but no trace of deposit was formed.

The zinc plates had a larger increase in weight when city water was used, the difference amounting to about 1 mg. on deposits weighing from 2 to 3 mg.

The galvanized-iron plates lost weight, the loss being smaller with the use of city water. This difference varied from 0.0 to 2.0 mg. on total losses of 0.8 to 4.0 mg.

The black-iron plates increased in weight from 1.5 to 6.5 mg. with city water, and lost 1.0 mg. in weight with the water containing caustic.

The inference from these experiments is that water containing caustic, in the amounts used in the experiments, does not contribute to a larger deposit than when no caustic is present.

An experiment was next made to discover whether the sodium carbonate treatment affected the deposit appreciably. A quantity of river water (50 gal.) was treated with lime cream, thoroughly agitated and settled, and the clear water was siphoned over weighed metals. At the same time city water, softened by both lime and soda, was run in duplicate apparatus, the conditions being kept similar in every way. The analyses are given in Table 35.

TABLE 35.

| | Chemical added. | Total alkalinity. | Phenol alkalinity. | Caustic alkalinity. |
|---|---|---|---|---|
| River water | None | 173 | 0 | 0 |
| City water | Lime and soda | 41 | 13 | 0 |
| Specially prepared water | Lime only. | 27 | 11 | 0 |

With the exception of the lead, deposits appeared on the metals and in the bottles, quite the same in the case of the water softened by lime and soda as in the water softened by lime only.

Mr. Sale. As the deposit obtained in the first experiment contained a large amount of carbonate, it was thought that any treatment of the water which would reduce the normal carbonates would effect good results. A powder, which proved to be sodium bicarbonate, called "American Carbonating Powder," was made the basis of many experiments, and sodium bicarbonate, likewise, was carried through similar tests. Preliminary experiments were made to see if the normal carbonates in the water were reduced by the use of these two chemicals, through liberation of carbonic acid gas. A typical experiment using each chemical is given here. This is corroborated by many others.

The conditions of the experiment were as follows: Nine ½-gal. bottles were filled with 3 liters of river water. Each bottle was then treated with a saturated solution of lime-water at the rate of 4¾ grains of calcium oxide per gallon. The bottles were then shaken for an hour, and then the soda, in soluble form, was added. The shaking was then repeated for an hour. After 24 hours standing, the supernatant liquid was siphoned through filters and analyzed. Erythrosine was used as an indicator in securing the total alkalinities. The details are given in Table 36.

TABLE 36.—REDUCTION OF NORMAL CARBONATES, IN PARTS PER MILLION.

| No. of sample. | CaO, in grains per gallon. | "American Carbonating Powder," in grains per gallon. | Sodium bicarbonate, in grains per gallon. | Total alkalinity. | Phenol alkalinity. | Caustic alkalinity. | Normal carbonates. | Maximum reduction of normal carbonates. |
|---|---|---|---|---|---|---|---|---|
| River water | 0 | 0 | 0 | 140 | 0 | 0 | 0 | ..... |
| 1 | 4¾ | 0 | 0 | 50 | 23 | 0 | 46 | ..... |
| 2 | 4¾ | 1 | 0 | 48 | 15 | 0 | 30 | ..... |
| 3 | 4¾ | 2 | 0 | 56 | 15 | 0 | 30 | ..... |
| 4 | 4¾ | 3 | 0 | 61 | 13 | 0 | 26 | 20 |
| 5 | 4¾ | 4 | 0 | 70 | 14 | 0 | 28 | ..... |
| 6 | 4¾ | 0 | 1 | 49 | 15 | 0 | 30 | ..... |
| 7 | 4¾ | 0 | 2 | 57 | 15 | 0 | 30 | ..... |
| 8 | 4¾ | 0 | 3 | 62 | 14 | 0 | 28 | ..... |
| 9 | 4¾ | 0 | 4 | 67 | 12 | 0 | 24 | 22 |

It will be noticed from Table 36, that there is a reduction in normal carbonates, and to practically the same extent with both the use of the "American Carbonating Powder" and the sodium bicarbonate.

To discover whether this reduction in normal carbonates might affect deposits on metals, many experiments were made of which the following is an example. The conditions of the experiment were as follows: A quantity of river water (50 gal.) was treated with lime cream of known strength, and agitated in the barrel by the stirring device for 1 hour. Sodium bicarbonate in solution was then added

in amount sufficient to give a water with a total hardness of about 100 parts per million calculated to carbonate of lime. This was followed by agitation for an hour, and, after settling for 24 hours, the clear water was siphoned over weighed metals as usual. At the same time a duplicate experiment was run, using tap water. The analyses are given in Table 37. Mr. Sale.

TABLE 37.

| Kind of water. | Gallons of water used. | CaO added, in grains per gallon. | $Na_2CO_3$ added, in grains per gallon. | $NaHCO_3$ added, in grains per gallon. | Total alkalinity, in parts per million. | Phenol alkalinity, in parts per million. | Normal carbonates, in parts per million. | Incrustants, in parts per million. | Mg, in parts per million. |
|---|---|---|---|---|---|---|---|---|---|
| City water | 50 | 5.9 | 0.2 | 0 | 41 | 14 | 28 | 54 | 12.9 |
| Specially treated water. | 50 | 6.25 | 0 | 2.3 | 67 | 3 | 6 | 56 | 16.3 |

The weights of the deposits formed are given in Table 38.

TABLE 38.

| | Lead (no deposit) increase in weight, in milligrammes. | Zinc, in milligrammes. | Black iron, in milligrammes. | Galvanized iron, in milligrammes. |
|---|---|---|---|---|
| City water | 0.4 | 7.8 | 9.0 | 8.4 |
| Specially treated water.. | 2.6 | 4.4 | 10.4 | 3.2 |

The lead in both cases increased somewhat in weight, but no deposit formed. The appearance of the deposits indicated a greater difference than the weights show, as the deposits are fluffy and occupy considerable space. As previously mentioned, the relative amounts can be judged closely by observation. The water treated with sodium bicarbonate is a more favorable water to use, as far as deposits on metal are concerned, but sufficient carbonic acid gas is not liberated to prevent deposition, even when so small a quantity of water as 50 gal. is used.

As sodium carbonate had proved inefficient in preventing deposition on metals, the well-known method of carbonating the filtered water was next tried. The apparatus set up for treating the water with carbonic acid gas was as follows: A hard glass tube, of 300 cu. cm. capacity, graduated in cubic centimeters, was fastened in an upright position. A two-holed rubber stopper was fitted to the lower end, one hole serving as the inlet for carbonic acid gas generated in a Kipp apparatus, the other attached by rubber tubing to a Mariotte

Mr. Sale.

bottle filled with water saturated with carbonic acid gas. The top of the tube was fitted with a one-holed stopper from which a bent glass tube led outward and down about 10 cm. To this arm a 10-cu. cm. pipette was connected by a short piece of rubber tubing. The pressure was controlled by the movable bottle, as in the case of an Orsat apparatus, and the flow of carbonic acid gas by pinch-cocks. A gallon bottle, filled with city water, was placed over the outflow, the pipette reaching to the bottom of the bottle. The top of the bottle was partly closed by close-fitting cardboard. The water was now carbonated very slowly, at the rate of about 10 bubbles per minute. When the desired amount of gas had passed into the water, the bottle of carbonated water was carefully removed, closed with a tight-fitting rubber stopper, and shaken for 5 min. At the end of that time it was transferred to a carboy and the proceeding was repeated. Two carboys, holding 25 gal., were filled for each experiment. Varying amounts of carbonic acid gas were passed into the water in the different experiments, the desire being to find the least amount of gas that would prevent deposition on metals. After the carboys were filled, the water was siphoned over plates of zinc and galvanized iron, as usual, at the rate of 1 gal. per hour for each kind of metal used. The results of the experiment are shown in Table 39.

TABLE 39.—ACTION OF CARBONATED FILTERED WATER ON ZINC AND GALVANIZED IRON.

| Liters of water treated. | $CO_2$ added per liter, in cubic centimeters. | Free $CO_2$ in treated water, in parts per million. | Loss in weight of zinc, in milligrammes. | Loss in weight of galvanized iron, in milligrammes. | Deposit on metals. | Deposit in bottles. |
|---|---|---|---|---|---|---|
| 100 | 100 | 63 | 58 | 56 | None. | None. |
| 100 | 33 | 19 | 14 | 15 | " | " |
| 100 | 20 | 14 | 17 | 17 | " | " |
| 100 | 13 | 10 | 5.6 | 2.4 | " | Slight. |
| 100 | 8 | 2 | 0.0 | 3.4 | Slight. | Large. |

It will be noticed from Table 39 that two figures may be chosen from the amount of carbonic acid gas to be passed into the water. Water carbonated at the rate of 20 cu. cm. of carbonic acid gas per liter will leave no deposit on metals; but the gas used in this quantity attacks the metals appreciably. Carbonic acid gas added at the rate of 13 cu. cm. per liter, on the other hand, leaves a very slight deposit, but the loss in weight of the metal is very much lower. Carbonic acid gas at the rate of 20 cu. cm. per liter would be about 325 lb. per million gallons. Pressure and temperature corrections were not made, as these experiments are roughly quantitative only.

The results of this study may be summarized as follows:

Mr. Sale.

*First.*—It is established that water softened by lime and soda and coagulated by alum or iron will appreciably attack zinc, black iron, and galvanized iron, and form heavy deposits.

*Second.*—In the case of zinc and galvanized iron, the deposits are similar in composition, and consist of about 90% of normal or basic carbonate of zinc.

*Third.*—Other salts present in the water in large quantities, such as carbonate of lime and magnesium, and sodium sulphate, are also present in the deposits to an appreciable extent, and are probably carried down by mechanical action.

*Fourth.*—Lead is practically unaffected, undergoing surface oxidation only, but receiving no deposit.

*Fifth.*—Black-iron pipe is heavily oxidized, copious deposits of iron oxide being formed and settling out to form a heavy sludge.

*Sixth.*—The dissolved oxygen in the water appears to have a corrosive action on the metals, which is aided by a carbonation, secured, first, either from the carbonic acid gas in the air, which is sufficient to form a normal or basic carbonate, but not sufficient to carry the deposit back into solution as bicarbonate; or, second, from the normal carbonates present in the filtered water, which are precipitated out as insoluble carbonate of zinc. No reduction in normal carbonates in the water that had passed over the metals could be detected, but so small a quantity as was taken for titration, namely, 100 cu. cm., would not bring out the difference.

*Seventh.*—A distilled water containing normal carbonate of lime forms deposits, indicating that this salt is a factor in the formation of deposits.

*Eighth.*—The same is true of carbonate of magnesium, to a less extent.

*Ninth.*—The presence of considerable amounts of sodium sulphate in the water does not appreciably affect the deposits.

*Tenth.*—Water containing considerable amounts of caustic favor the reduction of deposits.

*Eleventh.*—Sodium bicarbonate used as a chemical for the reduction of incrustants in water, that is, chlorides, sulphates, and nitrates of lime and magnesium, is no more nor less efficient than the normal carbonate of soda. Used as a chemical for the reduction of normal carbonates by the liberation of carbonic acid gas, it is efficient to the extent of about 20 parts per million. Used as a chemical for the prevention of deposits in pipes, it is unsatisfactory, reducing the deposits appreciably, but not eliminating them.

*Twelfth.*—Carbonation of the water is an efficient means of preventing the formation of deposits, but when used in sufficient amount the metals are attacked to an appreciable extent by the presence of free carbonic acid gas in the water.

Mr. C. P. Hoover.

C. P. HOOVER, ESQ.* (by letter).—In reference to Mr. Gregory's statement regarding the removal of bacteria, it might be of interest to state briefly some of the factors that influence bacterial removal at the Columbus Water Purification Works.

Bacterial removal at these works was governed in 1909 by, (*a*) the amounts of calcium and magnesium salts precipitated from the water; (*b*) the amount of coagulant added to the water; (*c*) the addition of calcium hypochlorite; and (*d*) the method of operating the filters.

*Removal of Bacteria by Water-Softening Precipitation.*—When the river water is very hard high bacterial efficiency is obtained by adding very little, or no coagulant. The precipitate of magnesium hydrate is gelatinous, and shows about the same degree of efficiency for the removal of bacteria, as the hydrate precipitates of iron and alumina. The precipitated carbonates are pulverulent, and are not as effective in the removal of bacteria. During January and the first thirteen days of February, dependence was placed entirely on the water-softening precipitation for the removal of bacteria. The effectiveness of this treatment is shown by Table 40, which gives the average amounts of magnesium hydrate and calcium carbonate precipitated from the river water, and shows the average bacterial counts in the river, settled, and filtered water, expressed in numbers per cubic centimeter. The bacterial removal was 99 per cent.

TABLE 40.

| Magnesium hydrate precipitated, in parts per million. | Calcium carbonate precipitated, in parts per million. | Bacteria per Cubic Centimeter. | | |
|---|---|---|---|---|
| | | River water. | Settled water. | Filtered water. |
| 70 | 308 | 540 | 31 | 5 |

*Removal of Bacteria by Coagulation.*—From the middle of February until the end of the year, either sulphate of iron or sulphate of alumina was added to the water. The quantities of coagulant added were proportioned by the amount and character of the turbidity, and varied from 0.3 to 8.3 grains per gallon. The average turbidity of the river water for the year has been 86 parts per million, and an average of 1.7 grains per gallon of coagulant has been added. Table 41 gives the average amounts of coagulant added to the river water.

The period of sedimentation was about 12 hours.

The number of bacteria in the river water during 1909 averaged 9 240 per cu. cm., in the settled water, 664, and in the filtered water, 120. These averages show that 92.8% of the total number of bacteria was removed in the settling basins, and that 5.9% more was taken out by filtering, making a total removal of 98.7 per cent.

* Asst. Chemist, Columbus Water Purification Works.

TABLE 41.

Mr. C. P. Hoover.

| Turbidity of river water between: | Coagulant added, in grains per gallon. | Turbidity of river water between: | Coagulant added, in grains per gallon. |
|---|---|---|---|
| 10 and 25 | 1.1 | 150 and 200 | 4.4 |
| 25 " 50 | 1.2 | 200 " 300 | 4.2 |
| 50 " 75 | 1.9 | 300 " 500 | 5.2 |
| 75 " 100 | 2.2 | 500 " 1 000 | 4.7 |
| 100 " 150 | 2.8 | 1 000 " 1 500 | 6.4 |

Table 42 shows the average of the daily counts, on the river, settled, and filtered water, for the year. The samples were plated in duplicate on agar, having an acidity of 1%, and were incubated for 48 hours at 20° cent.

TABLE 42.

| Month, 1909. | Average Number of Bacteria per Cubic Centimeter, in: | | |
|---|---|---|---|
| | River water. | Settled water. | Filtered water. |
| January | 435 | 12 | 4 |
| February | 33 000 | 2 100 | 80 |
| March | 18 000 | 800 | 80 |
| April | 8 500 | 850* | 250* |
| May | 16 500 | 3 500* | 700* |
| June | 4 000 | 180* | 120* |
| July | 4 000 | 42 | 13 |
| August | 1 900 | 85 | 29 |
| September | 1 200 | 65 | 23 |
| October | 700 | 100 | 23 |
| November | 1 300 | 60 | 76 |
| December | 21 500 | 65 | 11 |

* The large numbers of bacteria found in the settled and filtered waters during April, May, and June belonged to a species which grew in the settling basins.

Although the counts for the filtered water average 120 per cu. cm. for the year, the numbers were below 100 during 79% of the time; below 50 during 72% of the time; below 25 during 56% of the time; and below 10 during 39% of the time. On 20 days the plates were sterile.

The high numbers of bacteria, which appeared occasionally and hung on for two or three weeks at a time, were due, in almost all cases, to growths of a non-pathogenic bacterium, which develops in the lime sludge in the settling basins and conduits. The sludge contained about 5 000 000 or 6 000 000 bacteria per gramme, and every time this sludge was stirred up in the last chambers of the settling basins large numbers of bacteria were found in the settled and filtered water. The organism which caused the high counts will not grow at 37° cent. on any of the laboratory culture media, but develops on all media at 20° cent. Many times this organism caused the settling basin counts to be higher than the river water, and on a few occasions the filtered

Mr. C. P. Hoover.

water counts have been higher than those of the raw river water for a similar reason.

The counts on gelatin and agar have checked very satisfactorily at all times on the river water, and also on the settled and filtered water, except during times when there was trouble with these growths; then the gelatin plates showed many times as many of these tiny white colonies as were developed on agar.

*Disinfection with Calcium Hypochlorite.*—The first experiments were made in the laboratory, at a time when trouble was caused by growths in the settling basin. Four samples of settled water (1 gal. each) were collected in sterile bottles; the hypochlorite was added, and the samples were shaken vigorously for 15 min., then gelatin plates were poured. These plates were incubated at 20° cent. for 48 hours. The results of the hypochlorite treatment are given in Table 43.

TABLE 43.

| Sample No. | Available chlorine added, in parts per million. | Bacteria per cubic centimeter. |
|---|---|---|
| 1 | 0.0 | 20 000 |
| 2 | 0.25 | 112 |
| 3 | 0.50 | 10 |
| 4 | 0.75 | 1 |

On December 15th the treatment of the entire supply with calcium hypochlorite was commenced. The river was in flood, and the turbidity and numbers of bacteria were very high. Table 44 shows the numbers of bacteria found in the river water, the settled water, before the application of the hypochlorite, the treated settled water, the filtered water, and also the presence or absence of *B. Coli* in 1-cu. cm. and 50-cu. cm. portions of the filtered water.

There was considerable variation in the application of hypochlorite because of irregularity of pumping, and also on account of some mechanical difficulties with the dosing device.

Daily analyses were made for the determination of *B. Coli* in 1-cu. cm. portions of the river water and in 1-cu. cm. and 50-cu. cm. portions of the filtered water, according to the following procedure:

(*1*).—The filtered and river water samples, in 1-cu. cm. portions, were plated on lactose azolitmin Parietti agar, and after incubating 24 hours at 37° cent. four characteristic colonies, when present, were inoculated on agar slopes. From the slopes they were transferred into fermentation tubes of lactose bile (1% of lactose and ½% of peptone). If 25% of gas developed in the bile tube, then full determinative tests for *B. Coli* were made according to the procedure outlined in "Standard Methods of Water Analysis."

(*2*).—The samples, in 1-cu. cm. portions, were also inoculated into fermentation tubes of dextrose broth and lactose bile. The bile tubes

Mr. C. P. Hoover.

were incubated 48 hours at 37° cent., and if any gas developed lactose azolitmin Parietti agar plates were poured. Whenever present, characteristic colonies were transferred to agar slopes and tested for *B. Coli*. The dextrose broth tubes were incubated at 37° cent. for 24 hours and plates were poured from tubes showing gas. If the tubes showed no gas but had turbidity then 1 cu. cm. of the broth was transferred into a lactose bile tube and incubated 48 hours, plates being made if the tubes developed gas. All plates were fished, and cultures were treated as in Procedure *1*.

(*3*).—Samples of the filtered water, in 50-cu. cm. portions, were mixed with 10 cu. cm. of enrichment medium (a solution of dextrose broth of five times normal strength). The mixture was incubated at 37° cent. for 24 hours, and then 1 cu. cm. of the solution was transferred into a lactose bile fermentation tube which was cared for in the same way as in Procedures *1* and *2*.

TABLE 44.—NUMBERS OF BACTERIA PER CUBIC CENTIMETER WHICH DEVELOPED ON AGAR PLATES, INCUBATED 48 HOURS AT 20° CENT.

| 1909, December. | River water. | Settled water before treatment. | Settled water, treated. | Filtered water. | Av. Cl., in parts per million. | *B. Coli* PRESENT: | |
|---|---|---|---|---|---|---|---|
| | | | | | | 1 cu. cm. | 50 cu. cm. |
| 16 | 86 000 | 1 750 | 350 | 24 | .... | + | + |
| 17 | 61 000 | ..... | 70 | 22 | .... | 0 | 0 |
| 18 | 103 000 | ..... | 20 | 10 | .... | + | + |
| 19 | 77 000 | 3 600 | 255 | 28 | .... | 0 | + |
| 20 | 44 600 | 1 650 | 43 | 21 | 0.78 | 0 | + |
| 21 | 53 000 | 6 200 | 68 | 1 | 1.00 | 0 | 0 |
| 22 | 80 000 | 1 400 | 52 | 40 | 0.42 | + | + |
| 23 | 20 000 | 1 000 | 46 | 7 | 0.27 | 0 | 0 |
| 24 | 21 000 | 80 | 27 | 80 | 0.55 | 0 | + |
| 25 | 18 000 | 80 | 32 | 2 | 0.10 | 0 | 0 |
| 26 | 13 000 | 118 | 6 | 1 | 0.16 | 0 | 0 |
| 27 | 2 500 | 12 | 15 | 0 | 0.40 | 0 | + |
| 28 | 6 000 | 350 | 11 | 1 | 0.17 | 0 | 0 |
| 29 | 9 000 | 52 | 19 | 9 | 0.25 | 0 | + |
| 30 | 4 500 | 106 | 21 | 4 | 0.27 | 0 | 0 |
| 31 | 8 400 | 228 | 10 | 6 | 0.28 | 0 | + |

Table 45 shows the number of times that *B. Coli* were isolated from the river and filtered water from April 1st, 1909, to January 1st, 1910.

The filtered water, except on one or two occasions, has never given more than a bubble of gas in dextrose broth or in lactose bile, and no red colonies were ever found on lactose azolitmin Parietti agar. Dextrose broth tubes show some turbidity at times, and by transferring 1 cu. cm. of the broth into a lactose bile fermentation tube, there was sometimes obtained more than 25% of gas production; and on twelve occasions during the year it was possible to isolate *B. Coli* from 1-cu. cm. portions of the filtered water by the foregoing method. From 50-cu. cm. portions of the filtered water, *B. Coli* were isolated 43 times during the year, and on 26 different days. *B. Coli* were found to be present in 1-cu. cm. portions of the river water 71% of the time.

TABLE 45.—NUMBER OF TIMES *B. Coli* WERE ISOLATED FROM 1-CU. CM. PORTIONS OF RIVER AND 1-CU. CM. AND 50-CU. CM. PORTIONS OF FILTERED WATER, FROM APRIL TO DECEMBER, 1909.

| Date. | APRIL. | | | MAY. | | | JUNE. | | | JULY. | | | AUGUST. | | | SEPTEMBER. | | | OCTOBER. | | | NOVEMBER. | | | DECEMBER. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 cu. cm. R. | 1 cu. cm. F. | 50 cu. cm. F. | 1 cu. cm. R. | 1 cu. cm. F. | 50 cu. cm. F. | 1 cu. cm. R. | 1 cu. cm. F. | 50 cu. cm. F. | 1 cu. cm. R. | 1 cu. cm. F. | 50 cu. cm. F. | 1 cu. cm. R. | 1 cu. cm. F. | 50 cu. cm. F. | 1 cu. cm. R. | 1 cu. cm. F. | 50 cu. cm. F. | 1 cu. cm. R. | 1 cu. cm. F. | 50 cu. cm. F. | 1 cu. cm. R. | 1 cu. cm. F. | 50 cu. cm. F. | 1 cu. cm. R. | 1 cu. cm. F. | 50 cu. cm. F. |
| 1..... | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 6 | 0 | 0 |
| 2..... | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 4 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 |
| 3..... | 2 | 0 | 0 | 1 | 1 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 4 | 0 | 0 |
| 4..... | 0 | 0 | 0 | 5 | 0 | 2 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| 5..... | 0 | 0 | 0 | 5 | 0 | 1 | 3 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 1 |
| 6..... | 4 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 |
| 7..... | 3 | 0 | 0 | 4 | 0 | 0 | 7 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8..... | 0 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9..... | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 4 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| 10..... | 1 | 1 | 0 | 4 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 11..... | 2 | 0 | 0 | 4 | 0 | 0 | 1 | 0 | 0 | 4 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12..... | 1 | 0 | 0 | 5 | 0 | 0 | 3 | 0 | 0 | 4 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13..... | 3 | 0 | 1 | 4 | 0 | 0 | 5 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 |
| 14..... | 2 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 |
| 15..... | 4 | 0 | 1 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 1 | 1 |
| 16..... | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 5 | 1 | 3 |
| 17..... | 1 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 4 | 0 | 0 | 2 | 0 | 0 | 5 | 3 | 4 | 0 | 0 | 0 | 3 | 0 | 0 | 7 | 0 | 0 |
| 18..... | 0 | 0 | 0 | 6 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 3 | 1 |
| 19..... | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 3 |
| 20..... | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 1 |
| 21..... | 5 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 5 | 0 | 0 | 6 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| 22..... | 5 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 1 |
| 23..... | 0 | 0 | 0 | 7 | 0 | 0 | 4 | 0 | 0 | 5 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 1 |
| 24..... | 3 | 0 | 0 | 2 | 0 | 0 | 4 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 4 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 5 | 0 | 1 |
| 25..... | 2 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 |
| 26..... | 2 | 0 | 0 | 4 | 0 | 0 | 3 | 0 | 2 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 |
| 27..... | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 4 | 0 | 0 | 1 | 0 | 1 |
| 28..... | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 5 | 0 | 0 |
| 29..... | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 5 | 0 | 3 |
| 30..... | 0 | 0 | 0 | 4 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 1 | 0 | 0 |
| 31..... | .. | .. | .. | 2 | 0 | 0 | .. | .. | .. | 2 | 0 | 0 | 1 | 0 | 0 | .. | .. | .. | 0 | 0 | 0 | .. | .. | .. | 2 | 0 | 1 |
| Totals... | 41 | 1 | 2 | 96 | 1 | 5 | 95 | 0 | 3 | 74 | 0 | 0 | 55 | 0 | 0 | 59 | 3 | 12 | 38 | 0 | 1 | 23 | 0 | 0 | 101 | 7 | 20 |

Mr. C. P. Hoover.

C. B. HOOVER, ESQ.* (by letter).—A discussion of the results of the operation of the Columbus Sewage Purification Works is naturally divided into three parts: Mr. C. B. Hoover.

1.—Preliminary Treatment.
2.—Sprinkling Filter Treatment.
3.—Treatment in Final Sedimentation Basins.

It might be well to preface this discussion with a statement of the analytical methods and sampling schedule followed.

*Sampling Schedule.*—The screened sewage is sampled every 2 hours throughout the day and night, in amounts which are proportional to the volumes pumped at the times the samples are taken. This gives a composite sample which is a weighted mean for the 24 hours. The septic, filter, and settling basin effluents are sampled in equal amounts every 2 hours throughout the day and night, the twelve portions making up the composite samples for the 24 hours. Special samples for dissolved oxygen and bacteria are taken daily except Sunday. All other determinations are made on the composite samples. Composite samples, while being completed, are stored in a large refrigerator, and not poisoned.

*Analytical Methods.*—The standard methods for water and sewage analysis are followed.

Oxygen Consumed.—Permanganate to cold acidulated sample, then bring to a boil and continue boiling for 5 min.

Suspended Matter.—Gooch crucible method.

Nitrites and Nitrates.—Determined together by boiling 300 cu. cm. of sample to about 125 cu. cm., making up to 150 cu. cm. with ammonia-free water and the necessary amount of potassium hydrate, reducing at room temperature over night with aluminum foil, and nesslerizing without distillation.

Bacteria.—Counts of whole numbers made on 1.0% acid agar after 48 hours at 20° cent. and results expressed as millions per cubic centimeter.†

## PRELIMINARY TREATMENT.

The sewage received at the main purification works is made up of domestic and industrial wastes, with varying quantities of storm and ground-water, the trade wastes, under normal conditions, not being sufficiently large in volume to impress their character on the composition of the main volume of sewage. Table 46 gives the results of daily analyses of screened sewage from January 1st, 1909, to January 1st, 1910, and shows the maximum, minimum, and mean daily values.

*Chief Chemist, Columbus Sewage Purification Works.

†All analytical results are expressed as parts per million, unless otherwise stated.

Mr. C. B. Hoover.

TABLE 46.—RESULTS OF ANALYSES SHOWING RANGES IN COMPOSITION OF THE SCREENED SEWAGE.

| | Suspended matter. | Oxygen consumed. | Bacteria. |
|---|---|---|---|
| Maximum | 1 088 | 205 | 9.00 |
| Minimum | 13 | 7 | 0.08 |
| Mean | 200 | 61 | 2.37 |

The features of interest regarding the preliminary treatment may be discussed under the following headings:

*1.—Character and Amount of Septic Action Taking Place.*—The escape of gases, resulting from sludge decomposition, has at all times been very noticeable in the septic tanks. This visible evidence of septic action is more marked in the primary than in the secondary tanks. The primary tanks show the constant gentle boiling or escape of small volumes of gas coming from the decomposition of superficial material, and, at irregular intervals, the violent belching forth of large volumes of gas, carrying to the surface large amounts of sludge. This very violent action is probably due to the presence of large amounts of grit mixed with the sludge or deposited in it in layers which prevent the escape of small gas bubbles and favor an accumulation of the gas until the volume becomes sufficient to enable it to break through and escape in large amounts. Action of this kind is detrimental, as it interferes with the subsidence of sewage solids and favors a forward movement of the sludge. The secondary tanks show the gentle boiling, and, as there is but little grit deposited in these tanks, the violent belching is much less common.

There has never been any marked accumulation of scum on any of the septic tanks. On several occasions a typical scum formation has covered parts of the tanks, lasting for two or three days, but the tanks are so exposed, and present such a large surface for the wind to play upon, that scum formation does not proceed very far. One of the primary septic tanks, after standing idle for several weeks, developed a typical scum 3 or 4 in. thick, which lasted for about a week, and then apparently decomposed and disappeared.

*2.—The Efficiency of the Septic Tanks as Shown by the Removal of Suspended Matter and Bacteria.*—The only way in which the efficiency of the septic tanks can be affected is by varying the method of operating them. The design of the Columbus tanks is such that it is possible to have considerable variation in the method of operation. The efficiency of the tanks, as regards the removal of bacteria and suspended matter, and, also, the proper preparation of the sewage for subsequent treatment, is dependent, among other factors, on the length of the storage period.

Mr. C. B. Hoover.

TABLE 47.—THE FLEXIBILITY IN THE OPERATION OF THE SEPTIC TANKS MADE POSSIBLE BY THEIR DESIGN AND AS SHOWN BY THE VARIOUS STORAGE PERIODS OBTAINABLE, WITH THE MAXIMUM, MINIMUM, AND MEAN DAILY VOLUMES PUMPED DURING THE YEAR 1909.

| | POSSIBLE STORAGE PERIODS, IN HOURS FOR: | |
|---|---|---|
| Maximum volume pumped per 24 hours (21.4 million gallons). | Minimum volume pumped per 24 hours (3.1 million gallons). | Mean volume pumped per 24 hours (11.1 million gallons). |
| 8.3 | 41.0 | 16.0 |
| 7.6 | 37.5 | 14.6 |
| 6.9 | 34.0 | 13.2 |
| 6.2 | 31.0 | 11.8 |
| 5.7 | 28.0 | 10.8 |
| 4.9 | 24.0 | 9.4 |
| 4.2 | 21.0 | 8.0 |
| 3.5 | 17.0 | 6.7 |

The calculations in Table 47 were based on the mean elevation of the sewage in the septic tanks for the year 1909.

Another method of operating the tanks, which is made possible by their design, is a plan which has been followed to good advantage during the late spring, summer, and early fall months. It is as follows: One secondary and one or two of the primaries are used continuously until septic action becomes violent enough to interfere seriously with the subsidence of suspended solids, then these tanks are put out of service and the other secondary and primaries are put in service. The tanks which are put out of service are allowed to stand idle until the deposited sludge has been somewhat well digested. When this condition has been attained it will be indicated by the comparative absence of boiling, and a change in the color of the supernatant liquor from jet black to a clearer greenish color. The green color is due to a very luxuriant growth of *Uglena,* and this liquor has often been found to be supersaturated with dissolved oxygen, presumably as a result of the activities of these micro-organisms. When the tanks are shifted, the clear liquor in those which have been standing idle is drained into the river, and they are again ready for service. the sludge remaining in the tanks. The supernatant liquor which is drained into the river has been found to be non-putrescible and very low in bacteria (less than 10 000) and suspended matter. The character of the septic effluent is shown by Table 48, a summary of results of analyses made during 1909.

The average reduction by the septic tanks, for 1909, was:

Suspended matter .....58 per cent.
Oxygen consumed .....38 " "
Bacteria .....54 " "

Mr. C. B. Hoover.

TABLE 48.

| | Suspended matter. | Oxygen consumed. | Bacteria. |
|---|---|---|---|
| Maximum value..... | 230 | 132 | 6.45 |
| Minimum value..... | 12 | 7 | 0.04 |
| Mean value..... | 82 | 38 | 1.05 |

During 1909, in 8.1% of the bacterial counts, or 25 out of 306, the septic effluent was higher than the screened sewage, and in 3.6% of the suspended matter determinations, or 9 out of 249, the septic effluent was higher than the screened sewage.

The equalizing effect of the septic tanks is well shown by the results in Table 49.

TABLE 49.—AVERAGE DAILY DEPARTURE FROM THE MEAN DAILY SUSPENDED MATTER VALUE FOR THE MONTH.

| Month, 1909. | PARTS PER MILLION. | | PERCENTAGE. | |
|---|---|---|---|---|
| | Screened sewage. | Septic effluent. | Screened sewage. | Septic effluent. |
| January..... | 140 | 18 | 41 | 17 |
| February..... | 143 | 26 | 50 | 22 |
| March..... | 96 | 15 | 54 | 17 |
| April..... | 129 | 21 | 62 | 27 |
| May..... | 87 | 17 | 43 | 22 |
| June..... | 65 | 15 | 30 | 30 |
| July..... | 44 | 27 | 38 | 36 |
| August..... | 50 | 13 | 40 | 24 |
| September..... | 48 | 14 | 28 | 22 |
| October..... | 28 | 11 | 20 | 17 |
| November..... | 79 | 26 | 34 | 22 |
| December..... | 56 | 33 | 29 | 38 |
| Means..... | 80 | 20 | 39 | 24.5 |

Table 50 is a record of the amounts of sewage solids received by, and deposited in, the septic tanks during 1909.

*3.—Sludge Removal and Disposal.*—The composition of septic tank sludge is indicated by the results of analyses in Table 51.

Septic tank sludge is flushed into the river during flood times, the flow in the river at such times providing a dilution which is sufficient to oxidize the organic matter and render it inodorous. The dilution required by septic sludge depends on its age, composition, and the extent to which it has been decomposed in the tanks.

The variability in the stability of septic sludge, as indicated by the dissolved oxygen present after incubation for 48 hours at room temperature, is shown by Tables 52 and 53.

Mr. C. B. Hoover.

## TABLE 50.

| Month. | No. of Days. | Mean daily volume of sewage pumped. Million gallons. | Parts per Million. | | Pounds per Million Gallons. | | Tons per Million Gallons. | | Tons per Day. | | Tons per Month. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Screened sewage. | Septic effluent. | Screened sewage. | Septic effluent. | Screened sewage. | Septic effluent. | Screened sewage. | Septic effluent. | Screened sewage. | Septic effluent. |
| Jan. | 31 | 11.8 | 340 | 105 | 2 889 | 876 | 1.42 | 0.44 | 16.75 | 5.19 | 519 | 167 |
| Feb. | 28 | 15.2 | 285 | 120 | 2 380 | 1 000 | 1.19 | 0.50 | 18.10 | 7.60 | 507 | 213 |
| Mar. | 31 | 16.6 | 178 | 87 | 1 488 | 726 | 0.74 | 0.36 | 12.30 | 5.98 | 382 | 185 |
| Apr. | 30 | 12.1 | 209 | 78 | 1 745 | 650 | 0.87 | 0.33 | 10.50 | 3.99 | 315 | 120 |
| May. | 31 | 13.7 | 200 | 78 | 1 670 | 650 | 0.83 | 0.33 | 11.35 | 4.52 | 354 | 140 |
| June. | 30 | 13.4 | 214 | 49 | 1 787 | 410 | 0.89 | 0.21 | 11.90 | 2.82 | 357 | 85 |
| July. | 31 | 10.9 | 115 | 74 | 960 | 618 | 0.48 | 0.31 | 5.20 | 3.38 | 161 | 105 |
| Aug. | 31 | 9.8 | 126 | 55 | 1 052 | 460 | 0.53 | 0.23 | 5.10 | 2.25 | 158 | 70 |
| Sept. | 30 | 9.3 | 170 | 64 | 1 420 | 534 | 0.71 | 0.27 | 6.60 | 2.48 | 198 | 74 |
| Oct. | 31 | 9.0 | 141 | 63 | 1 175 | 525 | 0.58 | 0.26 | 5.28 | 2.36 | 164 | 73 |
| Nov. | 30 | 9.8 | 234 | 117 | 1 950 | 978 | 0.98 | 0.49 | 9.55 | 4.79 | 286 | 144 |
| Dec. | 31 | 11.7 | 192 | 88 | 1 600 | 734 | 0.80 | 0.37 | 9.35 | 4.29 | 290 | 133 |
| Sums. | 365 | *4.352 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3 691 | 1 509 |
| Means. | ..... | 11.9 | 200 | 82 | 1 665 | 684 | 0.83 | 0.34 | 9.9 | 4.0 | 308 | 126 |

* Billion gallons of sewage treated during 1909.

## TABLE 51.

| | Sludge from: | | | |
|---|---|---|---|---|
| | Primary tanks. | | | Secondary tanks. |
| Specific gravity. | 1.092 | 1.074 | 1.128 | 1.074 |
| Water. | 82.880% | 81.790% | 77.280% | ..... |
| Total solids. | 17.120% | 18.210% | 22.720% | 17.500% |
| Fixed solids. | 10.100% | 10.320% | 14.960% | 12.290% |
| Volatile solids. | 7.010% | 7.890% | 7.760% | 5.490% |
| Oxygen consumed. | 4.240% | 2.540% | 2.400% | 2.200% |
| Organic nitrogen. | 0.154% | 0.243% | 0.173% | 0.369% |
| Bacteria. | ..... | 73 000 000 | 78 000 000 | 33 000 000 |

## TABLE 52.

| Dilution: One part sludge in parts of water. | Dissolved Oxygen Present After 48 Hours at 20° Cent. | | |
|---|---|---|---|
| | Sample No. 1. | Sample No. 2. | Sample No. 3. |
| 100. | .... | 0.0 | 0.0 |
| 200. | .... | 0.0 | 0.0 |
| 250. | 0.6 | 0.0 | 0.0 |
| 300. | .... | 0.0 | 0.0 |
| 500. | 3.0 | 0.0 | 0.3 |
| 700. | .... | 0.0 | 0.8 |
| 750. | 4.2 | 0.0 | .... |
| 1 000. | 5.4 | 0.0 | .... |
| 1 200. | .... | 0.2 | .... |
| 1 500. | .... | 0.6 | .... |
| 2 000. | 7.3 | 1.9 | .... |
| 3 000. | .... | 3.4 | .... |

Mr. C. B. Hoover.

TABLE 53.

| Dilution: One part sludge in parts of distilled water. | Dissolved Oxygen and Odor After 24 Hours at 37° Cent. | | | | | |
|---|---|---|---|---|---|---|
| | Primary sludge. | | Secondary sludge. | | Settling basin sludge. | |
| | Dissolved oxygen. | Odor. | Dissolved oxygen. | Odor. | Dissolved oxygen. | Odor. |
| 50 | 0.0 | Positive. | 0.0 | Positive. | 0.0 | Positive. |
| 100 | 0.0 | " | 0.0 | " | 0.0 | " |
| 200 | 0.0 | " | 0.0 | Doubtful. | 0.0 | Negative. |
| 400 | 0.0 | Doubtful. | 0.0 | " | 2.6 | " |
| 600 | 0.0 | " | 0.0 | Negative. | 4.3 | " |
| 800 | 0.0 | Negative. | 0.0 | " | 5.1 | " |
| 1 000 | 0.0 | " | 0.0 | " | 5.9 | " |
| 1 200 | 0.0 | " | 1.2 | " | 6.2 | " |
| 1 400 | 1.0 | " | 1.4 | " | 6.3 | " |
| 1 600 | 1.0 | " | 2.4 | " | 6.5 | " |
| 1 800 | 1.6 | " | 2.5 | " | 6.5 | " |
| 2 000 | 2.3 | " | 3.2 | " | 6.1 | " |

Septic tank sludge at Columbus is disposed of at a cost of about ¼ cent per cu. yd. of wet sludge. This method of sludge disposal reduces the cost of handling sludge to a minimum, and is as justifiable, from a sanitary point of view, as is the discharge of the normal product of the works into the river during low-water stages. It possesses one element of uncertainty, however, as a long-continued low-water stage in the river in the future may make it desirable that land treatment be made available as an alternative. Table 54 shows the sludge disposal conditions during 1909.

TABLE 54.

| Days, during 1909, when the river was in condition to receive sludge. | Flow in the river, in cubic feet per second. | Number of days intervening between opportunities for sludge disposal. |
|---|---|---|
| February 15th and 16th | 840 to 3 300 | 77 |
| February 20th to 28th | 6 200 to 34 700 | 4 |
| April 6th, 7th, and 8th | 5 700 Mean. | 38 |
| April 30th, May 1st and 2d | 10 000 " | 22 |
| May 10th, 11th, 12th, and 13th | 9 800 " | 8 |
| August 16th and 17th | ..... | 95 |
| December 14th and 15th | 4 200 Mean. | 118 |

The following results of analysis show the typical composition of Scioto River water during flood stages:

| | |
|---|---|
| Dissolved oxygen | 12.6 |
| Oxygen consumed | 16.0 |
| Suspended matter | 350.0 |
| Chlorine | 5.0 |
| Bacteria | 75 000 |

Mr. C. B. Hoover.

*4.—Odor.*—In the winter there is practically no odor from the septic tanks, but there is always some during warm weather. In the summer the distance to which the odor is carried is governed almost entirely by weather conditions. Ordinarily, it cannot be detected for more than 200 yd. and, when it is detected farther than this, the distance depends on the velocity of the wind. The nearest dwelling to the works is a farmhouse, about 800 yd. distant. The nearest dwellings in line with the direction of the prevailing winds during May, June, and July, are from 1 to 1½ miles distant, and it is during August and September, when the prevailing winds are variable, that the nearest residents are apt to be annoyed.

## Sprinkling Filter Treatment.

Experience with the sprinkling filters at Columbus has emphasized certain things which seem to be essential to successful treatment of this kind. As a matter of convenience, these points will be discussed under appropriate headings.

*Sprinkling Nozzles.*—A good sprinkling nozzle should be designed so that it will possess the following qualities:

*1.*—It should show the slightest possible clogging tendencies.

*2.*—It should be very readily detachable, in order to facilitate cleaning.

These two points, according to experience at Columbus, are the most important, as the uniformity of the surface distribution is more dependent on the method of dosing and the spacing of the nozzles, than on the nozzle itself.

Nozzles of two types have been tried at Columbus, namely, that commonly known as the Columbus nozzle, and an armless nozzle in which the deflecting cone is the end of a spindle which passes down through the center of the orifice and is attached below. The latter has given the better satisfaction. Experience with the Columbus nozzle has shown: First, that the arms supporting the cone catch fibrous material, which breaks up the spray in such a way that wedge-shaped areas, in line with the arms, receive no sewage whatever; second, that material often catches on the point of the cone and interferes with the distribution; third, that the orifice should not be reduced to less than ½ in. in diameter; and fourth, that an improvement in the distribution is effected by having only one supporting arm.

During 1909 it was found that about 3.5% of the nozzles showed partly or completely obstructed sprays all the time. The design of the nozzle and the character of the applied liquor are the two factors which determine the extent to which troubles of this nature will occur.

*Surface Distribution.*—It is impossible to get uniform surface distribution with any fixed nozzle which is operated at any constant

Mr. C. B. Hoover.

head. Experience with the Columbus nozzle seems to warrant the following conclusions:

1.—The uniformity of the surface distribution will be a resultant of two factors, namely, method of dosing, and distance apart of nozzles.

2.—High heads are better than low, where a constant head must be used, and where the nozzles are spaced as they are at Columbus.

3.—The surface distribution may be made very satisfactory by using a properly designed dosing device which gives the right sequence of heads, with each head operating for the proper length of time.

Tables 55 and 56 give the results of tests showing the distribution effected by the Columbus nozzle at different heads. The values given are the volumes of liquor applied at given distances from the nozzle, in gallons per square foot per minute.

TABLE 55.

| Area within following radii, in feet | Head, in Feet. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1.0 to 1.5 | 0.07 | 0.013 | 0.012 | 0.012 | 0.0047 | 0.0114 | 0.0054 | 0.0101 |
| 1.5 to 2.0 | 0.67 | 0.06 | 0.03 | 0.023 | 0.0082 | 0.0120 | 0.0077 | 0.0125 |
| 2.0 to 2.5 | 0.77 | 0.21 | 0.07 | 0.05 | 0.0127 | 0.0175 | 0.0115 | 0.0156 |
| 2.5 to 3.0 | 0.13 | 0.38 | 0.14 | 0.08 | 0.0193 | 0.0246 | 0.0184 | 0.0203 |
| 3.0 to 3.5 | 0.02 | 0.35 | 0.23 | 0.14 | 0.0333 | 0.0370 | 0.0215 | 0.0287 |
| 3.5 to 4.0 | 0.007 | 0.16 | 0.22 | 0.18 | 0.0582 | 0.0528 | 0.0284 | 0.0374 |
| 4.0 to 4.5 | 0.003 | 0.05 | 0.20 | 0.20 | 0.0864 | 0.0745 | 0.0382 | 0.0496 |
| 4.5 to 5.0 | ..... | 0.015 | 0.11 | 0.17 | 0.1230 | 0.0984 | 0.0518 | 0.0620 |
| 5.0 to 5.5 | ..... | 0.006 | 0.053 | 0.11 | 0.1490 | 0.1239 | 0.0704 | 0.0783 |
| 5.5 to 6.0 | ..... | 0.002 | 0.024 | 0.05 | 0.1475 | 0.1357 | 0.0928 | 0.0962 |
| 6.0 to 6.5 | ..... | 0.0008 | 0.011 | 0.017 | 0.1200 | 0.1373 | 0.1308 | 0.1310 |
| 6.5 to 7.0 | ..... | ..... | 0.005 | 0.006 | 0.0708 | 0.1077 | 0.1600 | 0.1554 |
| 7.0 to 7.5 | ..... | ..... | 0.002 | 0.0017 | 0.0367 | 0.0900 | 0.1752 | 0.1750 |
| Total discharge per nozzle, in gallons per minute | 10.8 | 11.7 | 13.0 | 13.3 | 14.1 | 15.2 | 14.9 | 15.6 |
| Mean discharge, in gallons per square foot per minute for total area covered | 0.17 | 0.008 | 0.075 | 0.075 | 0.080 | 0.087 | 0.084 | 0.088 |
| Maximum rate, in millions of gallons per 24 hours | 48.3 | 23.5 | 14.4 | 12.5 | 9.3 | 8.6 | 11.0 | 10.97 |
| Minimum rate, in millions of gallons per acre per 24 hours | 0.19 | 0.05 | 0.125 | 0.106 | 0.29 | 0.71 | 0.34 | 0.63 |
| Mean rate | 10.7 | 5.5 | 4.7 | 4.7 | 5.0 | 5.4 | 5.3 | 5.5 |

*Filtering Material.*—The material used in the sprinkling filters is a mixture of Columbus and Delaware (lower and upper Corniferous) limestones, which belong to the Devonian Age. There is a small percentage of cherty particles mixed with the broken limestone, and, during the two winters through which the plant has been operated,

almost all of this chert in the surface stone has disintegrated. The breaking up of the chert no doubt takes place wherever such material is exposed to rain and cold, but proceeds very rapidly under the favoring conditions which exist in the sprinkling filters, and is probably caused by the leaching out of the interstitial carbonate of lime followed by freezing. Mr. C. B. Hoover.

TABLE 56.—RESULTS OF TESTS SHOWING THE DISTRIBUTION UNDER DIFFERENT METHODS OF OPERATION.

The values given are gallons per square foot per minute.

| Distance from nozzle, in feet. | EQUAL PERIODS OF TIME FOR: | | | *Dosing Tank, 10 ft. to 0 ft. | COLUMBUS NOZZLE, 5-FT. HEAD. SIZE OF ORIFICE, IN INCHES. | |
|---|---|---|---|---|---|---|
| | Heads of 3 ft., 6 ft., 9 ft. | Heads of 4 ft., 7 ft., 9 ft. | Heads of 10 ft. to 1 ft. | | $\frac{5}{16}$ | $\frac{7}{16}$ |
| 1.0 to 1.5 | 0.009 | 0.010 | 0.022 | 0.81 | 0.0067 | 0.003 |
| 1.5 to 2.0 | 0.027 | 0.014 | 0.124 | 0.72 | 0.007 | 0.007 |
| 2.0 to 2.5 | 0.079 | 0.027 | 0.067 | 0.56 | 0.011 | 0.013 |
| 2.5 to 3.0 | 0.140 | 0.054 | 0.072 | 0.43 | 0.021 | 0.034 |
| 3.0 to 3.5 | 0.137 | 0.097 | 0.075 | 0.41 | 0.044 | 0.064 |
| 3.5 to 4.0 | 0.085 | 0.114 | 0.072 | 0.36 | 0.083 | 0.106 |
| 4.0 to 4.5 | 0.065 | 0.104 | 0.070 | 0.37 | 0.140 | 0.130 |
| 4.5 to 5.0 | 0.067 | 0.092 | 0.068 | 0.37 | 0.190 | 0.093 |
| 5.0 to 5.5 | 0.078 | 0.085 | 0.066 | 0.37 | 0.192 | 0.047 |
| 5.5 to 6.0 | 0.082 | 0.087 | 0.061 | 0.38 | 0.114 | 0.020 |
| 6.0 to 6.5 | 0.084 | 0.090 | 0.067 | 0.42 | 0.072 | 0.010 |
| 6.5 to 7.0 | 0.075 | 0.085 | 0.063 | 0.45 | 0.028 | 0.0037 |
| 7.0 to 7.5 | 0.070 | 0.079 | 0.061 | 0.51 | 0.011 | 0.0034 |
| Means | 0.078 | 0.080 | 0.066 | 0.43 | 0.078 | 0.039 |
| Rate in gallons per acre per 24 hours — Mean | 4.89 | 5.02 | 4.14 | .... | 4.89 | 2.44 |
| Rate in gallons per acre per 24 hours — Max. | 8.78 | 6.18 | 7.77 | .... | 12.04 | 8.13 |
| Rate in gallons per acre per 24 hours — Min. | 0.56 | 0.63 | 1.38 | .... | 0.42 | 0.19 |

* Gallons per square foot, but not per minute.

*Clogging of Filtering Material.*—The analytical records for the year show as much suspended matter in the filter effluent as in the applied liquor, and examinations of the stones from top to bottom show them to be comparatively clean, the largest accumulation being noted within the first 8 in. The unloading of material is accomplished in two ways:

*First.*—There is always an unloading following a resting period, the longer the rest, as a rule, the more pronounced the unloading. When the filters are operated in such a way that long resting periods intervene between the dosing periods, this unloading becomes a daily feature of the work of the filter. When short (15 min. or less) resting

Mr. C. B. Hoover.

periods follow short dosing periods, this unloading is reduced to a minimum. Table 57 illustrates this point.

TABLE 57.

| Composite sample. | Filter No. 7. | | Filter No. 8. | |
|---|---|---|---|---|
| | Suspended matter. | Nitrites and nitrates. | Suspended matter. | Nitrites and nitrates. |
| | After a Rest Period of 28 Days (During May, 1909). | | | |
| First half hour | 615 | 27.96 | 1 750 | 28.08 |
| Second half hour | 208 | 9.78 | 214 | 9.55 |
| Whole day | 101 | 4.96 | 136 | 4.14 |
| | Same Filters After a 6-Hour Rest (April 26th, 1909) | | | |
| First 15 min | 604 | 6.29 | 498 | 4.40 |
| Second 15 min | 326 | 2.60 | 242 | 4.00 |
| Second half hour | 214 | 2.90 | 168 | 2.80 |
| Third " " | 174 | 2.90 | 124 | 2.80 |
| Fourth " " | 149 | 3.00 | 112 | 2.60 |
| | | | After a 15-Min. Rest. | |
| First 5 min | | | 92 | 5.50 |
| Second 5 min | | | 82 | 5.00 |
| Third 5 min | | | 77 | 5.00 |

*Second.*—There is an unloading which seems to be independent of the method of operation and is more pronounced in warm than in cold weather. This unloading is probably due to a combination of physical and biological forces, the suspended matter breaking loose from the stones and washing out after having accumulated in large amounts, which action is favored in the warmer weather by the increased activities of lower organisms which feed on the organic deposits.

The activities of the larva of *Psychoda alternata* (one of the moth flies the larva of which are very abundant in these deposits) seem to be especially favorable to this unloading, and, as these flies come and go in large numbers at irregular time intervals, their activities might explain the periodicity noted in the unloading.

The monthly analytical records show that, during the warm weather, there were one or more unloading periods of from 2 to 10 days duration each, per month.

*Methods of Operation.*—Intermittent operation, in which short dosing and resting periods (15 min. or less) alternate, has given by far the best results. The advantages of the short periods are as follows:

*1.*—A more uniform product from the filters.

*2.*—The filters are more quickly ripened and more easily kept in that condition.

*3.*—The establishment of conditions which seem to be most favorable to the activities of bacteria and other lower plant and animal organisms.

*4.*—A higher removal of whole numbers of bacteria.

Mr. C. B. Hoover.

*Composition of Effluent from Filters.*—The composition of the filter effluent during 1909 is shown in Table 58. The mean percentage removal of bacteria as well as the values for nitrites and nitrates are not as good as the results from the experimental Filters Nos. 7 and 8, which were operated on a short on-and-off schedule. This method of operation would have been applied to the whole plant had the volume of sewage been sufficient. Table 58 gives the comparative results, showing the difference in efficiency between Filters Nos. 1, 2, 3, 4, 5, and 6 and Nos. 7 and 8, as shown by the composition of the composite effluent from all the filters, and the effluent from Filters Nos. 7 and 8.

TABLE 58.

| Mean values for month of: | Applied Septic Effluent. | Filter Effluent. Composite Sample for All Filters. | | Effluent from Filter: | | | |
|---|---|---|---|---|---|---|---|
| | | | | No. 7. | | No. 8. | |
| | Bacteria. | Bacteria. | Nitrites and nitrates. | Bacteria. | Nitrites and nitrates. | Bacteria. | Nitrites and nitrates. |
| October, 1909 | 2.26 | 1.11 | 3.8 | 0.39 | 5.6 | 0.37 | 6.7 |
| November, 1909 | 1.86 | 0.72 | 4.0 | 0.43 | 10.0 | 0.43 | 9.2 |
| December, 1909, to the 11th | 1.23 | 0.46 | 3.1 | 0.44 | 8.5 | 0.44 | 7.5 |
| Mean | 1.94 | 0.90 | 3.6 | 0.41 | 8.0 | 0.40 | 7.8 |
| Bacterial reduction | | 53.6% | | 78% | | 78% | |

*Aeration.*—Table 59 gives the average values of thirty-one tests made on as many separate days during August, September, and October, 1909, and shows the amounts of dissolved oxygen, in parts per million, taken up in the spraying and passage through the filtering material, retained after flowing through the settling basins, and taken up between the settling basins and the river.

TABLE 59.

Dissolved Oxygen, in Parts per Million.

| Septic effluent. | Filter effluent. | Settling basin effluent. | Effluent when discharged into the river. | Percentage saturated when discharged into the river. |
|---|---|---|---|---|
| 0.0 | 5.6 | 2.6 | 4.5 | 48 |

The oxygen taken up between the settling basin and the river results from the churning which the effluent from the basins gets as it discharges into a bowl at the outlet.

TABLE 60.—MONTHLY SUMMARY OF ANALYTICAL RESULTS AND CONDITIONS OF OPERATION, OF THE COLUMBUS SEWAGE PURIFICATION WORKS FOR THE YEAR 1909.

| Month. | Temperature, in Degrees Fahrenheit. | | | | | | Rainfall (U.S. Weather Bureau Records, Columbus Station), in Inches. | | River Gauge, Elevation in Feet Above City Datum. | | | Volume Pumped, in Millions of Gallons per 24 Hours. | | | Average Period of Flow in Septic Tanks, in Hours. | | | Volume Filtered, in Millions of Gallons per 24 Hours. | | | Filter Area in Service, Average, in Acres, per 24 Hours. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Air. | | | Sewage. | | | | | | | | | | | | | | | | | | | |
| | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Total. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. |
| January..... | 66 | 4 | 32 | 56 | 51 | 55 | 0.39 | 2.52 | .... | .... | .... | 18.6 | 6.3 | 11.8 | 30.0 | 5.4 | 13.0 | 18.6 | 6.3 | 11.8 | 4.60 | 2.50 | 3.10 |
| February ... | 66 | 0 | 38 | 55 | 44 | 50 | 2.05 | 4.97 | 23.6 | .... | .... | 21.4 | 8.9 | 15.2 | 19.0 | 9.0 | 12.0 | 21.4 | 6.2 | 13.8 | 6.20 | 2.50 | 4.10 |
| March..... | 62 | 19 | 41 | 55 | 51 | 53 | 0.98 | 2.68 | .... | .... | .... | 20.1 | 10.2 | 16.6 | 16.0 | 9.5 | 11.6 | 20.1 | 4.4 | 16.1 | 4.90 | 2.50 | 4.00 |
| April..... | 84 | 23 | 54 | 61 | 51 | 56 | 1.00 | 3.20 | 14.3 | 7.1 | 8.3 | 17.7 | 5.4 | 12.1 | 36.0 | 10.5 | 16.9 | 16.8 | 4.3 | 11.5 | 4.50 | 2.10 | 3.10 |
| May..... | 87 | 34 | 60 | 63 | 53 | 58 | 1.12 | 4.65 | 18.6 | 7.5 | 10.3 | 18.1 | 6.4 | 13.7 | 28.8 | 10.0 | 14.4 | 17.9 | 1.8 | 12.2 | 4.40 | 0.42 | 3.07 |
| June..... | 94 | 47 | 73 | 71 | 63 | 67 | 1.01 | 3.88 | 11.4 | 6.6 | 8.7 | 17.0 | 10.4 | 13.4 | 17.5 | 6.5 | 10.6 | 16.9 | 10.4 | 13.4 | 3.75 | 2.50 | 3.10 |
| July..... | 95 | 51 | 75 | 70 | 63 | 67 | 1.11 | 3.34 | 10.3 | 6.2 | 7.0 | 18.4 | 5.2 | 10.9 | 14.4 | 4.3 | 7.9 | 18.4 | 5.0 | 10.4 | 3.55 | 1.40 | 2.40 |
| August..... | 95 | 49 | 77 | 72 | 68 | 69 | 1.69 | 2.53 | 12.8 | 6.0 | 7.1 | 13.2 | 8.6 | 9.8 | 8.6 | 5.5 | 7.8 | 13.2 | 8.6 | 9.8 | 2.80 | 1.65 | 2.13 |
| September.. | 92 | 40 | 68 | 69 | 65 | 67 | 1.49 | 1.81 | 7.0 | 5.8 | 6.0 | 10.6 | 8.0 | 9.3 | 8.1 | 6.1 | 7.4 | 10.6 | 8.0 | 9.3 | 3.05 | 2.05 | 2.56 |
| October..... | 84 | 31 | 52 | 65 | 61 | 63 | 0.68 | 2.77 | 6.5 | 5.7 | 5.8 | 10.0 | 8.0 | 9.0 | 8.8 | 7.0 | 7.8 | 10.0 | 8.0 | 9.0 | 3.60 | 2.37 | 2.88 |
| November... | 73 | 28 | 50 | 64 | 57 | 61 | 0.68 | 1.66 | 9.4 | 5.8 | 6.5 | 12.5 | 3.1 | 8.8 | 10.3 | 5.1 | 6.7 | 12.5 | 3.1 | 9.8 | 3.90 | 1.00 | 3.15 |
| December... | 68 | —6 | 26 | 61 | 47 | 55 | 0.49 | 2.58 | 13.7 | 6.4 | 7.5 | 13.5 | 9.4 | 11.7 | 6.9 | 4.7 | 5.5 | 13.5 | 9.4 | 11.7 | 3.85 | 1.35 | 2.80 |
| | 95 | —6 | 54 | 72 | 44 | 60 | 2.05 | 36.6 | 23.6 | 5.7 | 7.5 | 21.4 | 3.1 | 11.1 | 36.0 | 4.3 | 10.1 | 21.4 | 3.1 | 10.7 | 6.20 | 0.42 | 3.03 |

Mr. C. B. Hoover.

TABLE 60.—(*Continued.*)

| Month. | Average Rate of Filtration, in Millions of Gallons per Acre per 24 Hours. | | | Flow in Settling Basin, Average Period, in Hours. | | | Suspended Matter. Parts per million. | | | | | | | | | | | | Percentage removed by: | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Screened sewage. | | | Septic effluent. | | | Filter effluent. | | | Settling basin effluent. | | | Septic tanks. | Sprinkling filters. | Settling basin. | Whole system. |
| | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | | | | |
| January | 5.00 | 3.40 | 3.50 | 13.5 | 5.2 | 8.0 | 1 088 | 109 | 340 | 169 | 68 | 105 | .... | .... | .... | 81 | 28 | 50 | 70 | .. | .. | 84 |
| February | 4.70 | 3.10 | 3.90 | 7.5 | 3.5 | 5.0 | 814 | 58 | 285 | 230 | 70 | 120 | .... | .... | .... | 81 | 32 | 65 | 58 | .. | .. | 68 |
| March | 5.15 | 2.60 | 4.10 | 3.6 | 2.6 | 2.8 | 378 | 68 | 178 | 156 | 60 | 87 | 82 | 26 | 47 | 67 | 27 | 39 | 51 | 46 | 13 | 73 |
| April | 4.45 | 2.40 | 3.80 | 8.0 | 3.0 | 5.7 | 604 | 54 | 209 | 140 | 42 | 78 | 116 | 22 | 59 | 48 | 9 | 26 | 63 | 18 | 57 | 81 |
| May | 4.50 | 3.30 | 4.00 | 4.0 | 3.0 | 3.4 | 566 | 13 | 200 | 218 | 12 | 78 | 740 | 14 | 118 | 33 | 15 | 24 | 61 | 118* | 64 | 46 |
| June | 4.80 | 3.75 | 4.30 | .... | .... | .... | 366 | 96 | 214 | 101 | 31 | 49 | 148 | 21 | 56 | .. | .. | .. | 77 | 14* | .. | 74 |
| July | 5.40 | 3.00 | 4.35 | .... | .... | .... | 198 | 52 | 115 | 114 | 18 | 74 | 259 | 32 | 91 | .. | .. | .. | 36 | 23* | .. | 21 |
| August | 5.40 | 4.00 | 4.50 | .... | .... | .... | 305 | 61 | 126 | 118 | 31 | 55 | 213 | 17 | 75 | .. | .. | .. | 56 | 36* | 30 | 42 |
| September | 4.60 | 2.70 | 3.65 | 6.0 | 4.5 | 5.2 | 364 | 93 | 170 | 104 | 40 | 64 | 130 | 28 | 62 | 40 | 16 | 26 | 62 | 3 | 58 | 85 |
| October | 3.55 | 2.80 | 3.15 | 6.0 | 4.8 | 5.4 | 224 | 94 | 141 | 92 | 45 | 63 | 101 | 48 | 72 | 43 | 16 | 28 | 55 | 12* | 61 | 80 |
| November | 4.50 | 2.23 | 3.10 | 7.5 | 3.5 | 4.6 | 452 | 114 | 234 | 166 | 83 | 117 | 200 | 74 | 137 | 63 | 33 | 48 | 50 | 27* | 65 | 79 |
| December | 6.00 | 2.75 | 3.30 | 4.5 | 4.2 | 4.4 | 404 | 118 | 192 | 141 | 41 | 88 | 276 | 47 | 120 | 85 | 47 | 66 | 54 | 27* | 59 | 43 |
| | 6.00 | 2.23 | 3.84 | 13.5 | 2.6 | 4.9 | 1 088 | 13 | 200 | 230 | 12 | 82 | 740 | 14 | 84 | 85 | 9 | 41 | 58 | 18* | 51 | 65 |

*Percentage of increase over value of applied sewage.

In the last line of each part of this table: Under "Max." is given the maximum daily value; under "Min." is given the minimum daily value; under "Mean" is given the mean of the monthly means; under "Total" is given the sum of monthly totals; under "Neg.," "Doubt.," "Pos.," are given the means of the monthly values.

TABLE 60.—(*Continued.*)

| Month. | Oxygen Consumed, in Parts per Million. | | | | | | | | | | | | Final Effluent, in Parts per Million. | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Screened sewage. | | | Septic effluent. | | | Filter effluent. | | | Settling-basin effluent. | | | Chlorine. | | | Dissolved oxygen. | | | Nitrogen as nitrites and nitrates. | | | Incubated at 37 degrees cent. | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | After 24 hours. | | | | | | | | | Methylene Blue: Days required to decolorize 1 cu. cm. per 250 cu. cm. of effluent. | | |
| | | | | | | | | | | | | | | | | | | | | | | Nitrogen as nitrites and nitrates.* | | | Dissolved oxygen. | | | Odor, percentage. | | | | | |
| | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Neg. | Doubt. | Pos. | Max. | Min. | Mean. |
| January | 192 | 45 | 100 | 72 | 41 | 60 | .... | .. | .. | 43 | 18 | 30 | .. | .. | .. | 9.2 | 1.3 | 4.6 | 1.65 | 0.30 | 0.85 | .... | .... | .... | 0.0 | 0.0 | 0.0 | 36 | .. | 64 | .... | .... | .... |
| February | 100 | 7 | 53 | 62 | 18 | 35 | .... | .. | .. | 29 | 17 | 23 | .. | .. | .. | 10.6 | 5.2 | 8.0 | 7.90 | 0.50 | 2.68 | .... | .... | .... | 3.8 | 0.0 | 0.47 | 55 | .. | 45 | .... | .... | .... |
| March | 74 | 11 | 43 | 43 | 12 | 28 | 28 | 9 | 17 | 21 | 12 | 16 | .. | .. | .. | 11.7 | 6.2 | 9.7 | 11.90 | 1.20 | 5.00 | .... | .... | .... | 6.3 | 0.0 | 1.20 | 59 | .. | 41 | .... | .... | .... |
| April | 99 | 14 | 57 | 36 | 14 | 26 | 25 | 10 | 16 | 18 | 8 | 14 | .. | .. | .. | 11.5 | 0.6 | 6.2 | 7.80 | 0.90 | 2.65 | .... | .... | .... | 6.4 | 0.0 | 0.95 | 58 | .. | 42 | .... | .... | .... |
| May | 66 | 8 | 38 | 30 | 7 | 19 | 45 | 10 | 18 | 17 | 9 | 13 | 218 | 15 | 52 | 10.9 | 3.6 | 7.6 | 8.75 | 1.78 | 3.63 | .... | .... | .... | 6.2 | 0.0 | 1.27 | 60 | .. | 40 | .... | .... | .... |
| June | 74 | 16 | 46 | 40 | 13 | 24 | 19 | 9 | 13 | .... | .... | .... | 64 | 20 | 49 | 9.0 | 5.8 | 7.3 | 4.70 | 1.80 | 3.15 | .... | .... | .... | 3.5 | 0.0 | 0.62 | 67 | .. | 33 | .... | .... | .... |
| July | 67 | 19 | 38 | 47 | 14 | 29 | 51 | 11 | 20 | .... | .... | .... | 76 | 28 | 47 | 8.0 | 5.4 | 6.8 | 4.40 | 1.85 | 3.43 | .... | .... | .... | 3.4 | 0.0 | 0.67 | 69 | .. | 31 | .... | .... | .... |
| August | 70 | 17 | 42 | 45 | 13 | 32 | 31 | 11 | 18 | .... | .... | .... | 59 | 10 | 44 | 8.4 | 4.7 | 6.4 | 6.18 | 2.00 | 3.70 | .... | .... | .... | 4.4 | 0.0 | 0.91 | 81 | 19 | .. | .... | .... | .... |
| September | 87 | 50 | 69 | 51 | 28 | 44 | 36 | 19 | 24 | 22 | 11 | 16 | 73 | 50 | 65 | 5.6 | 1.5 | 3.7 | 5.80 | 1.00 | 3.27 | 100 | 0.0 | 50 | 1.5 | 0.0 | 0.27 | 65 | 27 | 8 | 7.00 | 0.29 | 4.17 |
| October | 79 | 51 | 64 | 54 | 36 | 45 | 33 | 18 | 26 | 20 | 12 | 16 | 75 | 57 | 64 | 7.2 | 3.4 | 5.8 | 5.50 | 2.80 | 3.80 | 92 | 0.0 | 31 | 1.0 | 0.0 | 0.28 | 76 | 16 | 8 | 7.00 | 1.00 | 5.78 |
| November | 122 | 32 | 62 | 81 | 26 | 44 | 43 | 13 | 29 | 25 | 10 | 16 | 87 | 55 | 69 | 7.6 | 4.3 | 6.3 | 6.50 | 1.70 | 4.00 | 92 | 3.8 | 33 | 2.2 | 0.0 | 0.60 | 61 | 26 | 13 | 7.00 | 0.59 | 5.00 |
| December | 205 | 75 | 115 | 132 | 28 | 72 | 43 | 14 | 26 | 25 | 20 | 23 | 83 | 29 | 55 | 12.7 | 3.7 | 9.1 | 7.00 | 0.10 | 4.10 | 100 | 0.0 | 51 | 1.3 | 0.0 | 0.40 | 54 | 29 | 17 | 7.00 | 0.50 | 4.20 |
| | 205 | 7 | 61 | 132 | 7 | 38 | 51 | 9 | 21 | 43 | 8 | 19 | 218 | 10 | 56 | 12.7 | 0.6 | 5.8 | 11.9 | 0.10 | 3.35 | 100 | 0.0 | 41 | 6.4 | 0.0 | 0.64 | 62 | 23 | 31 | 7.00 | 0.29 | 4.79 |

* Percentage reduced.

Mr. C. B. Hoover.

Mr. C. B. Hoover.

TABLE 60.—(*Continued.*)

WHOLE NUMBERS OF BACTERIA.

| Month. | Millions per cubic centimeter. | | | | | | | | | | | | Percentage reduced by: | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Screened sewage. | | | Septic effluent. | | | Filter effluent. | | | Settling-basin effluent. | | | Septic tanks. | Sprinkling filters. | Settling basin. | Whole system. |
| | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | Max. | Min. | Mean. | | | | |
| January | 5.92 | 1.10 | 2.70 | 2.30 | 0.22 | 0.90 | 2.52 | 0.24 | 0.80 | 1.96 | 0.30 | 0.80 | 66 | 14 | 13* | 67 |
| February | 3.00 | 0.03 | 0.95 | 0.80 | 0.05 | 0.35 | 0.75 | 0.16 | 0.35 | 0.90 | 0.24 | 0.45 | 63 | 20 | 11* | 68 |
| March | 2.92 | 0.15 | 1.18 | 1.52 | 0.04 | 0.55 | 1.07 | 0.08 | 0.43 | 0.89 | 0.22 | 0.50 | 54 | 26 | 14 | 80 |
| April | 5.00 | 0.16 | 1.57 | 1.44 | 0.04 | 0.74 | 5.30 | 0.11 | 0.90 | 1.94 | 0.11 | 0.71 | 53 | 9* | 21 | 58 |
| May | 6.80 | 0.23 | 2.20 | 6.45 | 0.10 | 1.30 | 2.55 | 0.18 | 0.80 | 1.44 | 0.14 | 1.00 | 37 | 46 | 0 | 70 |
| June | 9.00 | 0.72 | 3.65 | 2.63 | 0.57 | 1.29 | 1.02 | 0.19 | 0.52 | .... | .... | .... | 65 | 60 | .... | 86 |
| July | 5.77 | 0.36 | 1.35 | 1.12 | 0.08 | 0.54 | 0.41 | 0.08 | 0.17 | .... | .... | .... | 60 | 70 | .... | 87 |
| August | 2.20 | 0.24 | 0.93 | 0.88 | 0.10 | 0.46 | 0.28 | 0.02 | 0.12 | .... | .... | .... | 51 | 75 | 112* | 84 |
| September | 5.86 | 0.41 | 1.93 | 4.68 | 0.26 | 1.23 | 1.60 | 0.14 | 0.46 | 2.20 | 0.17 | 1.07 | 36 | 63 | 132* | 45 |
| October | 7.50 | 0.58 | 3.91 | 4.80 | 0.77 | 2.26 | 3.92 | 0.25 | 1.01 | 2.35 | 0.29 | 0.95 | 42 | 55 | 6 | 76 |
| November | 7.68 | 2.00 | 5.06 | 2.61 | 0.26 | 1.85 | 1.32 | 0.26 | 0.73 | 1.34 | 0.25 | 0.67 | 63 | 60 | 8 | 87 |
| December | 8.86 | 0.81 | 2.99 | 1.94 | 0.29 | 1.14 | 0.81 | 0.13 | 0.47 | 0.73 | 0.37 | 0.50 | 62 | 59 | 12 | 85 |
| | 9.00 | 0.03 | 2.37 | 6.45 | 0.04 | 1.05 | 5.30 | 0.02 | 0.56 | 2.35 | 0.11 | 0.74 | 54 | 45 | 21* | 74 |

* Percentage of increase over value of applied sewage.

In the last line of each part of this table: Under "Max." is given the maximum daily value; under "Min." is given the minimum daily value; under "Mean" is given the mean of the monthly means; under "Total" is given the sum of the monthly totals; under "Neg.," "Doubt.," "Pos.," are given the means of the monthly values.

Mr. C. B. Hoover.

The following results, giving the amounts of dissolved oxygen in parts per million, indicate the relative aerating efficiency of the spraying and trickling through the stone:

| | |
|---|---|
| Total in filter effluent | 6.6 |
| Spray caught in pan on surface of bed | 4.7 |
| Aeration due to trickling, by difference | 1.9 |
| Percentage of aeration due to spraying | 71.0 |

### Treatment in Final Settling Basins.

The efficiency of the final settling basins, as regards the removal of suspended matter and bacteria, is shown in Table 60. The settling basins remove suspended matter at all times, but the percentage removed is greatest during the times when the filters are unloading. This is shown in Table 61.

TABLE 61.—Mean Daily Value for Suspended Matter.

| Time. | Filter Effluent. | | Settling-Basin Effluent. | | Percentage Removed. | |
|---|---|---|---|---|---|---|
| | For whole month. | During unloading period. | For whole month. | During unloading period. | For whole month. | During unloading period. |
| April, 1909 | 59 | 110 | 26 | 27 | 57 | 75 |
| May, 1909 | 66 | 137 | 24 | 33 | 64 | 76 |
| September, 1909 | 62 | 106 | 26 | 38 | 58 | 64 |

The efficiency of the settling basins, as regards the removal of suspended matter, is governed by the following factors which are more or less interdependent.

*1.*—Character of the filter effluent.

Much suspended matter in filter effluent—high percentage of removal.

Little suspended matter in filter effluent—low percentage of removal.

*2.*—Length of the period of flow.

*3.*—Wind.

The basins are shallow, and strong winds retard the subsidence of material by keeping the water agitated.

*4.*—Septic action in sludge on floors of basins.

During warm weather the filter effluent loses about 50% of its dissolved oxygen during its passage through the basins, the amount of the loss being governed by the temperature, the length of the period of flow, the composition of the filter effluent, and the amount and condition of the deposited sludge. The results are shown in Table 59.

Mr. C. B. Hoover.

The composition of the settling basin sludge is indicated by the following results of analyses:

| | |
|---|---|
| Specific gravity | 1.051 |
| Water | 90.93% |
| Total solids | 9.07% |
| Fixed solids | 5.40% |
| Volatile solids | 3.67% |
| Organic nitrogen | 0.244% |
| Ferrous sulphide | 0.150% |
| Oxygen consumed | 1.27% |
| Bacteria (whole numbers) | 44 000 000 |

The stability of the settling basin sludge, as compared with septic tank sludge, is shown in Table 53. The stability of this sludge depends on its age; well-decomposed sludge can be treated on land without any danger whatever from offensiveness.

### Putrescibility of Final Effluent.

When the term putrescibility is used with reference to the condition of the final effluent from a sewage works, and each sample must be marked negative, doubtful, or positive, the writer suggests one of the following arbitrary standards:

*1.*—When 1 cu. cm. of a 0.1% solution of methylene blue is mixed with 250 cu. cm. of undiluted effluent and incubated at 37° cent.

Negative.—All samples not decolorized at end of 5 days.
Doubtful.—All samples decolorized in from 3 to 5 days.
Positive.—All samples decolorized in less than 3 days.

When the final effluent from the Columbus works is classified according to the above standard, the results of the ninety-one comparative tests for putrescibility made on the daily composite samples during September, October, November, and December, 1909, are as summed up in Table 62.

*2.*—When the undiluted effluent is incubated at 37° cent. for 24 hours.

Negative.—All samples showing 1.0 part or more of nitrogen as nitrite and nitrate.
Positive.—All samples showing less than 1.0 part of nitrogen as nitrite and nitrate.

When the putrescibility is based on the standard stated under Heading *2*, the results of the ninety-one comparative tests are as summed up in Table 63.

*3.*—When the undiluted effluent is incubated at 37° cent. for 24 hours.

Negative.—All samples showing a trace or more of dissolved oxygen.
Positive.—All samples showing no dissolved oxygen.

Mr. C. B. Hoover.

## TABLE 62.

| Methylene Blue Standard. | | Total Number of Samples That Were: | | |
|---|---|---|---|---|
| | | Non-putrescible. (52) | Doubtful. (14) | Putrescible. (25) |
| Odor | Negative | 39 | 10 | 10 |
| | Doubtful | 12 | 2 | 8 |
| | Positive | 1 | 2 | 7 |
| | Number of samples showing: | | | |
| Nitrogen as nitrites and nitrates, in parts per million. | 1.0 part or more | 52 | 12 | 4 |
| | Less than 1.0 part | 0 | 2 | 21 |
| | Mean amount in parts per million | 3.23 | 1.8 | 0.5 |
| | Number of samples showing: | | | |
| Dissolved oxygen, in parts per million. | Trace or more | 48 | 11 | 7 |
| | No dissolved oxygen | 4 | 3 | 18 |
| | Average amount, in parts per million | 0.50 | 0.54 | 0.11 |

## TABLE 63.

| Nitrite and Nitrate Standard. | | | Total Number of Samples That Were: | |
|---|---|---|---|---|
| | | | Non-putrescible. (68) | Putrescible. (23) |
| Odor | Negative | | 54 | 5 |
| | Doubtful | | 12 | 10 |
| | Positive | | 2 | 8 |
| Methylene Blue | Number of samples which held color for: | 7 days. | 47 | 0 |
| | | 6 " | 3 | 0 |
| | | 5 " | 2 | 0 |
| | | 4 " | 3 | 1 |
| | | 3 " | 9 | 1 |
| | | 2 " | 4 | 8 |
| | | 1 day | 0 | 6 |
| | | Less than 1 " | 0 | 7 |
| Dissolved Oxygen. | Number of samples which showed the following amounts, in parts per million: | 0.0 | 6 | 19 |
| | | 0.1 | 3 | 1 |
| | | 0.2 | 6 | 1 |
| | | 0.3 | 13 | 0 |
| | | 0.4 | 8 | 1 |
| | | 0.5 | 7 | 0 |
| | | 0.6 | 3 | 0 |
| | | 0.7 | 7 | 0 |
| | | 0.8 | 5 | 0 |
| | | 0.9 | 3 | 1 |
| | | 1.0 | 7 | 0 |

Mr. C. B. Hoover.

When putrescibility is based on the standard stated under Heading *3*, the results of the ninety-one comparative tests are as summed up in Table 64.

TABLE 64.

| Dissolved Oxygen Standard. | | | Total Number of Samples That Were: Non-putrescible. (66) | Putrescible. (25) |
|---|---|---|---|---|
| Odor. | | Negative | 50 | 9 |
| | | Doubtful | 13 | 9 |
| | | Positive | 3 | 7 |
| Methylene Blue. | Number of samples which held color for: | 7 days | 44 | 8 |
| | | 6 " | 3 | 0 |
| | | 5 " | 1 | 1 |
| | | 4 " | 3 | 1 |
| | | 3 " | 8 | 2 |
| | | 2 " | 6 | 6 |
| | | 1 " | 1 | 5 |
| | | Less than 1 day | 0 | 7 |
| | | Mean, in days | 5.85 | 2.40 |
| Nitrogen as Nitrites and Nitrates. | Number of samples which showed: | Less than 1.0 part per million | 4 | 19 |
| | | 1.0 part per million or more | 62 | 6 |
| | | Mean in parts per million | 2.86 | 0.67 |

The oxygen available is determined by multiplying the parts per million of nitrites and nitrates by 2.65 and adding the parts per million of dissolved oxygen. The factor, 2.65, was determined by taking the separate values for nitrites and nitrates, as determined from November 1st, 1908, to June 12th, 1909, getting the ratio existing between them, and applying this ratio to the available oxygen factors of 1.71 and 2.86 for nitrites and nitrates respectively.

*Conclusions.*

*1.*—The odor test is least desirable, because of its indefiniteness, which is caused by the personal equation necessarily introduced by the observer.

*2.*—The methylene blue test is best where such observations must be made by someone who is unskilled in chemical analysis.

*3.*—The dissolved oxygen test is the best of the analytical tests, from the standpoint of time and simplicity, and is no doubt most satisfactory where the time and equipment of the operator is limited. The minimum time required is 24 hours.

Mr. C. B. Hoover.

TABLE 65.—RÉSUMÉ OF RESULTS OF COMPARATIVE STUDIES OF THE VARIOUS STABILITY TESTS WHEN APPLIED TO NINETY-ONE DAILY COMPOSITE SAMPLES OF THE UNDILUTED FINAL EFFLUENT TAKEN DURING SEPTEMBER, OCTOBER, NOVEMBER, AND DECEMBER, 1909.

Temperature of incubation.....37° cent.
Period of incubation.....24 hours.

| Odor (after incubation). | | Percentage of Total Tests Which Were: | | |
|---|---|---|---|---|
| | | Negative. 64.8 | Doubtful. 24.1 | Positive 11.1 |

| Dissolved Oxygen (after incubation). | | Methylene Blue (after incubation). | | Nitrogen as Nitrites and Nitrates (after incubation). | |
|---|---|---|---|---|---|
| | | 1 cu. cm. of a 0.1% solution per 250 cu. cm. of effluent. | | | |
| Parts per million. | Percentage of total tests showing: | Time. | Percentage of total tests holding color. | Parts per million. | Percentage of total number of samples showing: |
| 0.0 | 27.5 | 7 days. | 51.6 | 0.0 | 5.5 |
| 0.1 | 4.4 | 6 " | 3.3 | 0.0 — 0.5 | 14.3 |
| 0.2 | 7.7 | 5 " | 2.2 | 0.5 — 1.0 | 5.5 |
| 0.3 | 14.3 | 4 " | 4.4 | 1.0 — 1.5 | 8.8 |
| 0.4 | 10.0 | 3 " | 11.0 | 1.5 — 2.0 | 7.7 |
| 0.5 | 7.7 | 2 " | 13.2 | 2.0 — 2.5 | 16.5 |
| 0.6 | 3.3 | 1 day. | 6.6 | 2.5 — 3.0 | 5.5 |
| 0.7 | 7.7 | Less than 1 day. | 7.7 | 3.0 — 3.5 | 15.4 |
| 0.8 | 5.5 | | | 3.5 — 4.0 | 8.8 |
| 0.9 | 4.4 | | | 4.0 — 4.5 | 2.2 |
| 1.0 or more. | 7.7 | | | 4.5 — 5.0 | 1.1 |
| | | | | 5.0 — 5.5 | 6.6 |
| | | | | 5.5 — 6.0 | 1.1 |
| | | | | 6.0 — 6.5 | 0.0 |
| | | | | 6.5 — 7.0 | 0.0 |
| | | | | 7.0 — 7.5 | 1.1 |

RESTATEMENT.

| | | | | | |
|---|---|---|---|---|---|
| 0.0 | 27.5 | 7 days | 51.6 | 0.0 | 5.5 |
| 0.1 or more. | 72.5 | 6 days or more. | 54.9 | 0.5 or more. | 81.2 |
| 0.2 " " | 68.1 | 5 " " " | 57.1 | 1.0 " " | 74.7 |
| 0.3 " " | 60.4 | 4 " " " | 61.5 | 1.5 " " | 65.9 |
| 0.4 " " | 46.1 | 3 " " " | 72.5 | 2.0 " " | 58.2 |
| 0.5 " " | 36.1 | 2 " " " | 85.7 | 2.5 " " | 41.7 |
| 0.6 " " | 28.4 | 1 day " " | 92.3 | 3.0 " " | 36.2 |
| 0.7 " " | 25.1 | Less than 1 day. | 7.7 | 3.5 " " | 20.8 |
| 0.8 " " | 17.4 | | | 4.0 " " | 12.0 |
| 0.9 " " | 11.9 | | | 4.5 " " | 9.8 |
| 1.0 " " | 7.7 | | | 5.0 " " | 8.7 |
| | | | | 5.5 " " | 2.1 |
| | | | | 6.0 " " | 1.0 |

TABLE 66.—RÉSUMÉ OF PRECEDING TABLES.

Mr. C. B. Hoover.

| | | Nitrite-Nitrate Standard. | | Dissolved Oxygen Standard. | | Methylene-Blue Standard. | | | Odor Test. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P. | N. | P. | N. | P. | D. | N. | P. | D. | N. |
| | | (23) | (68) | (25) | (66) | (25) | (14) | (52) | (10) | (22) | (59) |
| Oxygen available from nitrites, nitrates, and dissolved oxygen. | Max. | 2.75 | 15.7 | 7.95 | 15.7 | 6.89 | 7.86 | 15.7 | 3.44 | 15.2 | 15.7 |
| | Min. | 0.00 | 2.65 | 0.00 | 1.72 | 0.00 | 0.79 | 2.65 | 0.00 | 0.0 | 0.0 |
| | Mean. | 0.89 | 8.22 | 1.77 | 8.13 | 1.33 | 5.25 | 9.06 | 1.42 | 4.75 | 7.8 |
| Mean time, in days, required to decolorize methylene blue. | | 1.56 | 6.00 | 2.40 | 5.85 | 1.49 | 3.63 | 6.89 | 2.14 | 3.76 | 5.75 |

*4.*—The "nitrite nitrate" test is best where the time and equipment of the operator will permit. The minimum time required is 30 hours. Its advantages over the dissolved oxygen test are as follows:

*A.*—There is always a definite minimum amount (1.0 part of nitrogen as nitrite and nitrate equivalent to 2.65 parts of oxygen) of available oxygen left in the sample.

*B.*—It gives lower available oxygen values for putrescible samples and higher values for non-putrescible samples, as shown by the mean values in Table 66.

A. ELLIOTT KIMBERLY, ESQ.* (by letter).—As Mr. Gregory has limited his paper chiefly to features of design and construction, it seems to the writer that it may be of interest to give a short review of some of the broader aspects of the problem, an account of some of the preliminary studies, and to mention a few points regarding features of operation and results accomplished. Mr. Kimberly.

Both the Water Purification and the Sewage Purification Works represent a decided advance in the art of water treatment and sewage purification as applied to large-scale municipal problems. For the first time in the United States water is softened as well as purified in a municipal plant of large capacity. For the first time also, mechanical filters are used to clarify the softened and settled water, as opposed to the use of cloth, presses, and rapid filters or strainers composed of a variety of materials.

At the sewage works there are many innovations attributable to an intimate knowledge of local conditions afforded by the elaborate experimental work conducted at the Columbus Sewage Testing Station.

* Cons. Engr. and Chemist, Columbus, Ohio.

Mr. Kimberly.

These great works have been successful in solving two great sanitary problems, and reflect great credit on the consulting engineers responsible for the type of construction used, and on the designing engineer responsible for the details, and their actual construction and completion as far as the operating stage.

*Water Purification Works.*—The water problem at Columbus, as indicated by the design of the plant, has two main purposes, namely, to remove the bacteria and the turbidity from the river water and to eliminate a portion of the hardness. For many years Columbus had a high typhoid fever death rate, due to the polluted character of the water of the Scioto River from which the major portion of the public water supply was derived. Studies leading to an improvement in the supply were necessarily directed toward the maintenance of a potable water at all times. It was also recognized that the Scioto River, which, at times, has a total hardness of 500 parts per million because of its mineral content, was not satisfactory for a public water supply without softening, even though, by filtration, it should be rendered free from disease germs. The hard water formerly supplied gave rise to the general use of soft water cisterns, double plumbing in residences, and heavy annual outlays on the part of property owners for repairs to rain-water pumps and fixtures, due to the incrusting property of the hard public supply.

The combined softening and purification of a river water of varying composition was practically a new development in water purification, and naturally required certain preliminary studies, especially with regard to the water-softening features and their application to a practical municipal plant. Although funds were not available to carry out such exhaustive tests of the water-softening problem as was the case with regard to the sewage, yet, in connection with the regular work of the Testing Station, from September 15th to December 31st, 1904, small-scale tests of the softening of the Scioto River water were made. The results of these tests were submitted to Julian Griggs, M. Am. Soc. C. E., then Chief Engineer of the Board of Public Service, in a report prepared by George A. Johnson, Assoc. M. Am. Soc. C. E. In this report there were a number of suggestions regarding the design and operation of the softening devices, many of which are embodied in the plant as ultimately constructed and as at present operated. It may be of interest, therefore, to abstract, from this unpublished report, some of the more important facts brought out by these tests, as follows:

*1.*—The presence of magnesium in the Scioto River water necessitates the use of unusual quantities of lime.

*2.*—It is neither possible nor practicable to reduce the alkalinity of the raw Scioto River water to a figure much lower than 37 parts per million.

*3.*—It is not necessary nor wise to attempt the complete removal of the incrustants, and it is suggested that from 40 to 50 parts per million of the incrustants be allowed to remain in the treated water. Mr. Kimberly.

*4.*—It is more feasible to apply the lime as lime-water, as it can be kept under control better than if a concentrated suspension of lime were used.

*5.*—It is advisable that the lime be added to the water a sufficient period of time prior to the application of the soda ash to allow of a thorough mixing of the lime with the water. This procedure will apparently effect a more complete lime reaction, and will materially increase the efficiency of the total softening action.

*6.*—Indications are strong that the minimum period of reaction should be one hour. During this reaction period it is vitally necessary that the water be kept in constant agitation in order to maintain in suspension the forming precipitates.

*7.*—The tests strongly indicate the advisability of applying the total quantity of lime required for the total quantity of water to a major portion, but not to all, of the raw water. They also indicate that this procedure will greatly accelerate the initial softening reactions, will effect a more complete removal of magnesium, and will tend to reduce the undesirable feature of residual causticity.

*8.*—Subsequent to the application of the softening chemicals, settling basins are necessary to remove a substantial percentage of the suspended precipitates, to compensate for irregularities in the application of the softening chemicals, and to complete the softening action.

*9.*—To guard against residual causticity, a small percentage of raw water may be added to the softened water.

*10.*—The design of the devices for softening the water should be flexible, particularly with regard to periods of subsidence following periods of reaction, and prior to the application of the coagulated water to the filters.

Attention to these features regarding the softening of a magnesium water, typified by that in the Scioto River, is the explanation of some of the essentials in the design of the Columbus plant. These refer to the splitting of the discharge of the low-service pumps at the head-house, a portion being over-treated with lime in the so-called saturators, a portion being discharged directly into the reaction tanks, a portion being applied, together with the soda ash, at a point in the reaction tanks one-fourth of the distance from the inlet, and a small portion being capable of diversion to the coagulating basins in order to prevent an excess of causticity in the treated water.

The well-known fact that agitation, together with the forming precipitates in the water throughout the period of treatment, is very beneficial, has been recognized in the design by providing reaction tanks in which the velocity is intended to be sufficiently great to maintain in suspension the greater part of the forming magnesium hydrate and carbonate of lime.

Mr. Kimberly.

A study of the results of the first 8 months of operation at the Columbus Water Purification Works, as presented by Mr. Gregory, indicates that Columbus now has a satisfactory public water supply, not only potable, as indicated by the absence of disease organisms, but moderately soft, corresponding in hardness to that of the public supplies in New England and the larger cities of the East.

The analytical data further suggest that in the operation of the Columbus Water Purification Works there are, according to the condition of the river, two distinct types of treatment: When the river is in flood, as indicated by the high turbidities, the quantity of softening chemicals required is greatly reduced, and there are times when the raw water is so soft that no lime or soda ash is applied. Under such conditions one type of treatment is illustrated, namely, the removal of turbidity and bacteria, the usual function of a mechanical filtration plant. The second general type of treatment refers to times when the water in the Scioto River is of low turbidity and about or above the average hardness, under which conditions the softening features predominate. Under the first conditions, the coagulant, sulphate of alumina or lime and iron plus sedimentation, effects the clarification of the water and the removal of the bacteria. In the second instance, clarification and bacterial removal are effected by the combined action of lime and soda ash plus sedimentation, assisted occasionally by the secondary application of small quantities of coagulant.

In the experimental studies of the water-softening problem at Columbus, it was developed that at times the Scioto River water contains sufficient magnesium to be self-coagulating on the addition of lime, and that magnesium is a most important element in the treatment of the water, as it forms a gelatinous precipitate of high entraining power due to the action of lime. So potent is the water-softening precipitate, under normal conditions, that a very high removal of bacteria is effected by the settling basins alone. A practical conclusion to be drawn from these facts, which are revealed by a study of the operation data for Columbus and as observed by the writer at the municipal water-softening plant at Oberlin, Ohio,* is that, for hard magnesium waters of moderate turbidity, subsequent filtration largely refers to the clarification of the softened and settled water and less to the removal of bacteria.

During floods in the Scioto River, however, a reverse condition appears to exist. The magnesium in the raw water falls to a small quantity, the natural coagulant is absent, and there are necessary the usual practices in the operation of mechanical filter plants under flood conditions, with accompanying high numbers of bacteria and high turbidity in the raw water. Under these conditions dependence is placed on the filters to supplement the bacterial removal accomplished

* Special Report, Ohio State Board of Health, 1908, p. 353.

by the settling basins, as is the case in the operation of filter plants which include no water-softening features. Mr. Kimberly.

There is another feature regarding the water treatment at Columbus which appears to merit some attention, that is, the over-treatment, as provided by the design. Small-scale tests, carried out at the Sewage Testing Station, indicated strongly that the speed of the softening would be higher, and that the net efficiency of the softening treatment would be greater, if a portion of the water were over-treated with lime. Under ordinary conditions, such a practice develops a copious magnesium flock, and causes the formation of a marked precipitate in that portion of the water thus over-treated, with a result that the softening of the remainder of the water is accomplished much more thoroughly and speedily.

It is a comparatively simple matter to soften a water of constant composition, for example, a deep-well supply, and it is accomplished readily by numerous proprietary devices now on the market. When the hard water, however, is a river water, subject to frequent rapid and extreme changes in chemical, bacterial, and physical characteristics, the control of a water-softening plant requires constant, careful, and expert supervision, and experienced judgment. The excellent results which have been obtained at the Columbus Water Purification Works, seem to the writer to reflect great credit on the superintendent in charge of its operation. The Columbus plant has the best of facilities for the examination of the treated water at different stages in the process, and, by standard methods of analysis, its operation is most carefully watched, the result being that the citizens of Columbus are obtaining an excellent supply of drinking water, remarkably free from bacteria and intestinal organisms, and of good appearance.

Others will probably discuss the marked reduction in typhoid fever and in general mortality brought about by this much-needed municipal improvement. It occurs to the writer, however, to mention (as stated in the report of the Local Board of Health for 1909) that there were 170 deaths from typhoid fever in Columbus in 1908, and only 20 deaths in 1909. On the basis of a population of 178 000 in 1908 and 186 500 in 1909, this represents a reduction from 95.5 to 10.7 per 100 000—certainly a most striking testimonial to the great value of a pure public water supply.

*Sewage Purification Works.*—The great value of the preliminary experiments at Columbus seems to the writer to be clearly demonstrated when one considers the variety of projects proposed for the solution of this sewage problem and the considerable saving in cost made possible by a plant in which close knowledge of local conditions was directly applied in its design.

In considering the status of the art of sewage purification prior to the experiments at the Columbus Sewage Testing Station in 1904-05,

Mr. Kimberly.

it will be recalled that while treatment of crude or settled sewage on filters constructed of fine-grained material had been developed thoroughly from the scientific side at Lawrence, and in practice in many New England cities, processes applicable to large-scale problems for inland cities, where the glacial drift formation is absent, had scarcely passed the experimental stage, save, perhaps, from numerous somewhat conflicting experiences in England with combinations of sedimentation devices and filters of coarse grain, variously operated.

There can be no question of the direct bearing of the results of the experiments at the Columbus Testing Station upon the design of the present plant, and, considering more recent developments at Baltimore, Reading, Washington, Pa., and at a number of other places, the results have influenced, in a large measure, the design of later plants intended to cope with sewage-treatment problems of considerable magnitude.

The uncertainties in the application of the practice current at that time to the Columbus problem are well illustrated by noting that all the consulting engineers employed at Columbus prior to 1904 suggested the construction of a part of the plant at first, and that the entire works be completed, provided the initial installation proved satisfactory. It is interesting to recall that this practice has been quite common in England since the beginning of the coarse-grained filter era of sewage treatment, dating from 1892 or thereabouts.

In discussing the historical side of the problem at Columbus, Mr. Gregory has apparently overlooked the fact that in 1900, two years after Messrs. Griggs and Alvord submitted their report recommending screening and double filtration through coke, the Board of Sewer Commissioners submitted for the consideration of the State Board of Health the proposition to pass the Columbus sewage through twelve septic tanks, each of 500 000 gal. capacity. This project was disapproved by the Board for the following reasons*:

"First—That there would be a possibility of open septic tanks of the size proposed creating a nuisance.

"Second—That the septic tanks alone would not prevent pollution of the river at times of low water.

"Third—That the cost of artificial filters necessary to purify the septic tank effluent would be excessive and the life of such filters would be uncertain.

"Fourth—That there was a lack of exact scientific knowledge as to the septic tank process under varying conditions and with different sewages."

The Board strongly urged an experimental study of the problem in order to determine the character of the Columbus sewage and the best method of purifying it. Later, the Board approved Mr. Hering's

* Report of Ohio State Board of Health, 1905, p. 128.

plan for septic tanks and sand filters, but advised a partial installation, with a view to practical experimentation. Mr. Kimberly.

It has seemed to the writer that it may be of interest again to state some of the more important results of the Columbus experiments, especially those which have largely controlled the design of the plant. The following are among the important features regarding which sound data were developed at the Testing Station:

*1.*—Volume of sewage flow.
*a.*—Average. *b.*—Dry-weather. *c.*—Storm.
*2.*—Composition of the Columbus sewage.
*a.*—Strength. *b.*—Influence of manufactural wastes.
*3.*—Maximum economical removal of suspended matter by various preparatory treatments.
*4.*—Economical period of flow in settling tanks.
*5.*—Advisability of flexible settling-tank design, and arrangement of tanks on the compartment plan.
*6.*—Substantial agreement of plain sedimentation and the septic process as regards the removal of suspended matter.
*7.*—Absence of over-septicization tendencies in the Columbus sewage in tanks holding a 24-hour flow.
*8.*—Non-appearance of well-defined scum upon the septic tanks.
*9.*—Absence of marked odors from the septic tanks.
*10.*—Feasibility of sludge disposal by dilution in the Scioto River during flood stages.
*11.*—Quantity of accumulating sludge to be expected from the several preparatory treatments.
*12.*—Impracticability of coke strainers, on account of rapid clogging.
*13.*—Impracticability of chemical precipitation for Columbus conditions.
*14.*—Feasibility of treating screened and settled sewage on sand filters at a rate of from 250 000 to 300 000 gal. per acre in 24 hours.
*15.*—Impracticability of satisfactory results from single contact filters of broken stone, 5 ft. thick, at rates greater than 600 000 to 700 000 gal. per acre in 24 hours.
*16.*—Feasibility of obtaining a non-putrescible effluent by applying screened and settled Columbus sewage to sprinkling filters of broken stone, 5 ft. in depth, the sewage applied by stationary nozzles under a head of 4.0 ft.
*17.*—Feasibility of operating open sprinkling filters under winter conditions in Columbus.
*18.*—Ability of sprinkling filters to unload stored clogging matters and thus make the period of their usefulness longer than is true of contact filters under similar conditions.
*19.*—Feasibility of improving the appearance of the effluents of the sprinkling filters by a short period of sedimentation.

Carefully weighing the available evidence, Mr. Johnson recommended preliminary clarification of the screened sewage in basins holding about 8 hours' flow, purification of this screened and settled

Mr. Kimberly.

sewage on sprinkling filters, 5 ft. deep, to which the sewage was to be applied at an average net rate of 2 000 000 gal. per acre per 24 hours, and final clarification of the effluent from the sprinkling filters in basins holding an average flow of about 2 hours. Broadly speaking, such are the principal features recommended by the consulting engineers.

Commenting on the analyses illustrating the daily results accomplished by the plant from January to August, 1909, Mr. Gregory alludes to a possibly severe interpretation of the test used at the plant to indicate the efficiency of the works in converting to a stable form the organic matters dissolved in the crude Columbus sewage. It does not seem surprising that the purification, in the early history of the operation of the Columbus plant, was perhaps not as high as desirable. The necessity for the time element or the ripening period in sewage filters is, of course, well understood, and, to the writer, the analytical data shown in the paper clearly illustrate this feature. Furthermore, it is to be recalled that in the early operation of the plant winter conditions prevailed, and these generally tend to lower the efficiency of purification works, even when such works have become matured by long service.

A study of the tabulated analytical data in the paper will suggest a steady improvement in the character of the final effluent from the plant as its period of service increased and as warmer temperatures increased the bacterial activity.

During the work at the Testing Station a number of studies* were directed toward the question of putrescibility and the possibility of an interpretation of the ordinary analytical data to indicate the ultimate stability of the effluent. These studies aimed to correlate the quantity of oxygen required to render stable the readily putrescible matters in the effluent, and the quantity of oxygen present in the effluent as free dissolved oxygen, nitrites and nitrates, or what may be called the "available oxygen." It was found that the required oxygen indicating the readily putrescible matters is very closely 20% of the oxygen consumed; that the available oxygen is the sum of that present as nitrites and nitrates together with an uncertain percentage of dissolved gaseous oxygen.

In Table 67 the analytical data in Mr. Gregory's paper are arranged to indicate the oxygen required to overcome putrescence and that available for this purpose from the sources above mentioned. The data are presented as weekly averages from January 1st, to June 10th, 1909, that is, up to the time nitrites and nitrates ceased to be separately determined. The results in the table are expressed in parts of oxygen per million. The required oxygen is considered to be 20%

* *Journal*, Infect. Dis. Sup. No. 2, Feb., 1906, pages 89-95.

of the oxygen consumed. Nitrite and nitrate oxygen, respectively, are computed by multiplying the reported results by the respective factors, 1.71 and 2.86. The sum of these two products plus a varying percentage of the dissolved gaseous oxygen appears to be the potential protection of the effluent against putrefactive tendencies. Mr. Kimberly.

It is not the intention to discuss the putrescibility features, nor to contrast deductions from these chemical data with the odor tests shown in the paper, but to illustrate the gradual improvement in the character of the effluent from the sprinkling filters under continued operation and with the advent of warmer weather. The oxygen data in Table 67 strikingly indicate the maturing feature and a gradual gain in available oxygen, and therewith a reduction in the required oxygen. It is interesting to note the marked effect on the character of the effluent due to the rest of 8 days in the latter part of February and of 4 days in May.

TABLE 67.—PURIFICATION EFFECTED BY COLUMBUS SEWAGE PURIFICATION WORKS, BY WEEKS, JANUARY 1ST TO JUNE 10TH, 1909, AS INDICATED BY QUANTITY OF OXYGEN PRESENT AS DISSOLVED NITRITES AND NITRATES, RESPECTIVELY, TOGETHER WITH COMPUTED QUANTITY OF OXYGEN REQUIRED TO OVERCOME PUTRESCENCE.

| 1909. | Average minimum air temperature, in degrees Fahrenheit. | Oxygen, in Parts per Million. | | | | | |
|---|---|---|---|---|---|---|---|
| | | Nitrites. | Nitrates. | Dissolved. | Nitrites + nitrates. | Required.* | Nitrites + nitrates + dissolved oxygen. |
| Jan. 1-7 | 25 | 0.2 | 1.4 | 3.8 | 1.6 | 6.5 | 5.4 |
| Jan. 8-14 | 20 | 0.2 | 1.3 | 5.0 | 1.5 | 6.9 | 6.5 |
| Jan. 15-21 | 27 | 0.3 | 1.8 | 4.7 | 2.1 | 6.1 | 6.8 |
| Jan. 22-28 | 40 | 0.4 | 2.9 | 3.9 | 3.3 | 5.2 | 7.2 |
| Jan. 29-Feb. 4 | 18 | 0.4 | 2.5 | 7.8 | 2.9 | 5.7 | 10.7 |
| Feb. 5-11 | 31 | 0.9 | 3.4 | 6.7 | 4.3 | 4.6 | 11.0 |
| Feb. 12-18 | 27 | 1.2 | 5.4 | 6.3 | 6.6 | 3.2 | 12.9 |
| Feb. 19-25 | 33 | .... | .... | .... | .... | .... | .... |
| Feb. 26-Mar. 4† | 33 | 1.7 | 21.7 | 11.2 | 23.4 | 3.0 | 34.6 |
| Mar. 5-14 | 35 | 1.5 | 17.2 | 10.4 | 18.7 | 3.8 | 29.1 |
| Mar. 12-18 | 28 | 1.4 | 13.4 | 10.4 | 14.8 | 3.0 | 25.2 |
| Mar. 19-25 | 32 | 1.0 | 4.3 | 8.4 | 5.3 | 4.2 | 13.7 |
| Mar. 26-Apr. 1 | 33 | 0.6 | 6.6 | 8.5 | 7.2 | 2.8 | 15.7 |
| Apr. 2-8 | 40 | 0.5 | 3.5 | 5.9 | 4.0 | 3.0 | 9.9 |
| Apr. 9-15 | 35 | 1.4 | 10.3 | 9.4 | 11.7 | 3.0 | 21.1 |
| Apr. 16-22 | 49 | 1.0 | 5.1 | 5.9 | 6.1 | 2.6 | 12.0 |
| Apr. 23-29 | 38 | 1.0 | 5.4 | 4.1 | 6.4 | 2.8 | 9.5 |
| Apr. 30‡-May 6 | .... | .... | .... | .... | .... | .... | .... |
| May 7-13§ | .... | .... | .... | .... | .... | .... | .... |
| May 14-20 | 51 | 1.4 | 11.4 | 8.8 | 12.8 | 3.0 | 21.6 |
| May 21-27 | 54 | 1.4 | 5.7 | 7.3 | 7.1 | 2.6 | 14.4 |
| May 28-June 3 | 62 | 0.9 | 5.1 | 6.8 | 6.0 | 2.4 | 12.8 |
| June 4-10 | 63 | 1.0 | 8.3 | 7.3 | 9.3 | 2.8 | 16.6 |

*Oxygen consumed × 0.2. †Filters rested, February 21st to 28th, inclusive. ‡Filters rested, May 1st to 4th, inclusive. §Filters rested, May 10th to 13th, inclusive.

Mr. Kimberly.

Considering the analytical control under which the Columbus plant is operated, it is apparent (and true also of many other sewage plants and of investigations of the sewage purification problem, both in experiment stations and in practical plants in actual operation) that particular attention is directed to what may be called the scientific phase of the purification accomplished. That is to say, the merits of the plant are judged by the actual keeping qualities of the effluent *per se*, without regard to the practical results which the plant produces with respect to the stream it has been designed to protect. It seems to the writer that more weight should be attached to the examination of streams above and below the outlets of sewage purification works than has been true in the past. In other words, it would appear desirable to obtain more definite information than now appears to exist regarding the stream which receives the plant effluent, especially during those periods when, without the plant, a serious nuisance would develop.

It is apparent that, in the case of the Columbus plant, the required degree of purification may vary widely from that of mere screening during floods to treatment on sprinkling filters, respectively, with and without sedimentation of the effluent from the sprinkling filters as a final step. Measurements of stream flow and periodic analyses of the stream above and below the plant seem to the writer particularly desirable, and this information may readily be secured at large plants where technical supervision is available. Possibly the discussion of operation data by the officials in charge may throw some light on the matter, regarding conditions at the Columbus plant.

Through personal observation, the writer considers that there can be no question that the Columbus sewage works have abated the nuisance which for a number of years existed in the Scioto River below the former outlet of the intercepting sewer. Information available from the continued operation of the Columbus plant is of great value in advancing knowledge of the treatment of sewage by sprinkling filters, especially as the solution of sewage disposal problems involving public nuisances in smaller watercourses is becoming more and more important in the Middle West, where the high cost of fine-grained filtering material generally necessitates other methods of sewage treatment than the well-understood sand filtration process adaptable to conditions in the East.

Mr. Rideal.

SAMUEL RIDEAL, ESQ.* (by letter).—As a record of the experience gained during the first year of service, this paper is exceedingly interesting, and the City of Columbus is to be congratulated on obtaining in so short a time such a great improvement in its water supply, and on the ability which has been shown in the construction and management of the water and sewage works.

* Cons. Chemist, London, England.

Mr. Rideal.

At present the writer understands that the raw water is treated with a considerable quantity of chemicals, comprising solutions of lime, soda ash, and coagulant (sulphate of iron or sulphate of alumina), and then settled, as is done in ordinary processes of treatment for industrial purposes, and that finally, "when desired," a small quantity of raw water is added prior to filtration, in order to eliminate traces of caustic alkalinity. That some such expedient was necessary is shown by the fact that during the first three months the caustic alkalinity in the filtered water was often 20 parts per million or more, reaching, in one case, 37 parts; though in the latter period it was usually absent. A well-known rule in the trade treatment of water is that the reagents shall be adjusted so that the product will not show any caustic reaction with phenolphthalein, and this appears to be still more important in the case of drinking water; in this case, it is questionable whether the addition of raw water is an allowable method of attaining the object.

In the two mixing tanks, the management of the supplies and the arrangement of the baffles to prevent sedimentation and to keep the solids in suspension until the chemical reactions are completed, seem to be especially good. Examining the analytical figures, for February, 1909, in Table 12, the writer notices that although the Scioto River is pronounced to be "hard," its total and permanent or "incrustant" hardness are generally about the same as those of the Thames, and of a degree which, in England, would not demand any softening for a general supply; it is also noted that the use of soda ash in addition to lime and coagulant has the advantage of not increasing the permanent hardness (incrustants), as lime and coagulant alone do; on the other hand, it has replaced the natural (carbonate of lime) alkalinity of the water by an average of 30 parts per million of carbonate of soda, and, of course, also produces sulphate of soda. Such a change is here probably of no great hygienic importance, but a short time ago, in a discussion of the purification at Steelton, Pa.,* the writer suggested sodium aluminate as effecting softening and clarification with an addition of less chemicals to the water. It is clear that this substance dispenses with all the sulphuric acid of the aluminium or iron sulphate, together with the soda or lime often required to neutralize it. The aluminate was strongly recommended by Mabery and Baltzley,† in 1899, as fulfilling all the conditions for softening and clarification. Lack of time prevents the writer from discussing other points in connection with this agent.

A hint in the paper as to the principles on which the chemicals are applied would have been welcome; it is evidently not in proportion to the turbidity, as in February, 1909, the latter was 256, in April, 102,

* *Transactions*, Am. Soc. C. E., Vol. LXVI, p. 206.

† *Journal*, Am. Chem. Soc., Vol. XXI, p. 23.

Mr. Rideal.

and in May, 196, while the respective quantities of coagulant used in those months were 1.8, 2.4, and 3.9 grains per gallon. The only explanation is that "the chemical solutions are fed automatically in proportion to the quantity of raw water pumped into the head-house." No organic analyses of the water are given. It is noted that *B. Coli* was present in 50 cu. cm. of the filtered water on 20 days during the 8 months recorded.

The difficulty caused by the water increasing rapidly in turbidity in periods of flood while decreasing in hardness, and, therefore, at the same time, undoubtedly altering greatly in bacterial character, points to the disadvantage of a system sometimes adopted, and, perhaps, in this case, hard to avoid, of converting the river itself into a reservoir, ponding it by means of a dam, and necessarily receiving all the flood water without control. The construction of lateral storage reservoirs on the Scioto, as on the Thames and other rivers, might be worthy of consideration; this would allow more time for sedimentation, would equalize the quality, and would provide, as Houston and others contend, for the natural elimination of pathogenic organisms. However, as it is known that *B. Coli*, and presumably also more dangerous forms, are not certainly removed by sand filtration, it would be better to save time and expense, and attain security by practical sterilization with chlorine or ozone, since the experience of their success is so general. Such a procedure is supported by J. M. Diven, Assoc. Am. Soc. C. E., in the recent discussion on Mr. Fuertes' paper.* The Lawrence, Mass., report of 1904, may also be quoted: "with the city mechanical filter, using sulphate of alumina as a coagulant, the tests for *Coli* in the filtered water were frequently positive."

The special points in the arrangement of the sewage works at Columbus seem to be the passage of the sewage through two sets of septic tanks, "primary" and "secondary," and the provision of final settling basins with scum-boards. Even with these amplifications, the suspended solids reach an average of 46 parts per million, which is higher than the limit regarded as generally satisfactory by the British Royal Commission, namely, 30 parts, while such heavy figures as 364 and 740 occur in the effluent from the filters, and 67 in that from the final settling basins. The tables, however, show that, on the whole, the results at the works are improving.

Mr. Potter.

ALEXANDER POTTER, ASSOC. M. AM. SOC. C. E.—Those who have visited the public improvements at Columbus, Ohio, cannot but express their appreciation of Mr. Gregory's very complete description of the work constructed under his supervision. It is to be regretted, however, that the author did not see his way clear to co-operate with those responsible for the design of the plant and with those in charge of the

* *Transactions*, Am. Soc. C. E., Vol. LXVI, p. 215.

Mr. Potter.

plant during the first year's operation in order to include the operators' complete analysis of the results obtained, and also the designing engineers' interpretation of these results. The correlative study of the constructed work, with the results expected and those obtained from such works, would undoubtedly call for a more responsive and more valuable discussion, for, in the speaker's opinion, there is little that is essentially new at Columbus, which cannot be discussed more intelligently from the standpoint of the results expected and those obtained.

In studying results of the plant the first item requiring comment is the bacterial reduction in the settled water and the occasional collapse of the settling basins as a means for the removal of bacteria. An examination of Table 12 shows that, on February 17th, the river water contained 100 000 bacteria, while the settled water contained 50 000. On March 1st, the river water contained 32 500, while the settled water contained 17 000. On April 24th, the river water contained 1 250, while the settled water contained 5 000. On May 12th, while the river water contained 35 000, the settled water contained 36 500. When it is remembered that the settling basins, outside of these unusual conditions, will remove 95% of the bacteria, it will be extremely valuable to have the opinion of those responsible for the design of the plant as to the cause or causes of these anomalous conditions, and a suggestion as to the remedy. An examination of the tables will also show that the conditions at work to bring about these unusual results in the settling tank were of such a nature as to cause the collapse of the filter itself. For instance, on May 9th, there were 320 bacteria in the river water, 7 500 in the settled water, and 5 850 in the filtered water. On April 25th there were 2 000 bacteria in the river water, 1 000 in the settled water, and 1 250 in the filtered water.

An explanation of the occasional collapse of the settling basins in the performance of their work may be the accumulation of the sludge on the side slopes sloughing off over large areas of the basins. There is deposited daily in the settling basin 60 000 lb. of clay and chemical precipitates. On the assumption that the sludge is 90% water, there is deposited on these side slopes daily an amount of sludge varying from 1⅜ in. at the bottom to zero at the top, at least, in the basin in which the treated water is first introduced. It is hardly conceivable that this material would move uniformly and continuously down the slope, and it is difficult to know just how thick a deposit would occur on the sloping sides of the settling basin before it would slough off. On more than 41% of the total area of the settling basin the sludge falls on the slopes; while, in the first basin into which the water is introduced, 68% of the area over which precipitation occurs consists of side slopes. It must also be remembered that a portion of these side slopes is paved with stones, offering a better medium for the retention

Mr. Potter.

of the sludge for a longer time than if the slope walls were constructed with a smooth concrete surface. Under these conditions, it is inconceivable that the sludge collecting on the slopes should flow uniformly to the bottom of the basins. If it descends *en masse,* it will doubtless cause trouble.

The changes in temperature of the water are not sufficient to cause an overturning of the water and the disturbance of the sludge in the bottom, and thus explain the sudden rise in the number of bacteria in the settled water, although the temperature might have had something to do with the collapse in February, when the conditions shown in Table 68 were found.

TABLE 68.

| Day of month. | Temperature, in Degrees Fahrenheit: | | Bacteria per Cubic Centimeter: | | |
|---|---|---|---|---|---|
| | Air. | Water in settling basin. | River water. | Settled water. | Filtered water. |
| Feb. 14, 1909..... | 45 | 39 | 17 500 | 400 | 15 |
| Feb. 15, 1909..... | 33 | 37 | 16 000 | 50 | 6 |
| Feb. 16, 1909..... | 26 | 37 | 50 000 | 250 | 80 |
| Feb. 17, 1909..... | 22 | 25 | 100 000 | 50 000 | 500 |
| Feb. 18, 1909..... | 33 | 35 | 60 100 | 1 000 | 800 |

The speaker had hoped that the results obtained at Columbus would corroborate those obtained at the water-softening plant at McKeesport, Pa., where the turbidity in the raw water is practically eliminated in the settled water, and where a high percentage of removal of bacteria in the settled water is uniformly obtained. A corroboration of these results might point the way to the elimination of the filter where water-softening processes are in use, its place being taken by sterilization with hypochlorite of lime or soda. The purification obtained in the settling basins in the McKeesport plant was of a higher degree than that obtained at Columbus, but whether this more favorable result was due to the difference in the design or the presence of a natural coagulant in the water at McKeesport, the speaker's investigations have not covered a sufficient period to enable him to state authoritatively at present. The principal differences in the design of the settling tank, which may be responsible for the better results at McKeesport, are as follows: The omission of sloping walls; provision for the removal of sludge without emptying the basins; a means for removing sludge from those portions of the bottom where the depth of deposit demands it, without disturbing the remainder of the settling basin; the arrangement of the tanks so that the velocity through them is 60% less than the velocity through those at Columbus. If sterilization of the treated water was found to yield a satisfactory efflu-

ent without filtration, approximately 40% of the cost of constructing the Columbus plant could have been saved, and the cost of operation could have been reduced fully 30 per cent. It is a problem worthy of careful consideration. Mr. Potter.

Turning to the sewage disposal problem, it is interesting to note the close similarity between the results predicted for the septic tanks, from the experimental work conducted under the direct supervision of George A. Johnson, Assoc. M. Am. Soc. C. E., on behalf of the City of Columbus, and the actual results obtained in practice. It was stated, as a result of these experiments, that about two-thirds of the suspended matter could be removed by the septic tanks. According to the actual results obtained, about 60% of this suspended matter is removed. It will be interesting to know whether this reduction was brought about by using these tanks as straight septic tanks, or whether they were used along the general lines recently adopted in other cities in an effort to evade the Cameron septic tank patents.

As opposed to the relatively close agreement between experiment and practice in the septic tanks, a wide difference in the actual bacterial efficiency of the whole plant is found, for which an explanation will no doubt be made by those responsible for the design and operation. As a result of the experimental work, a bacterial purification of 90% was predicted. The actual percentage of removal is 68.

As a result of experiments it was assumed that no odors would be noticed $\frac{1}{4}$ mile from the plant, but, unfortunately, odors are perceptible at much greater distances.

The speaker hopes that this important public improvement will be discussed fully by the designing and operating engineers, and that the practical working of the "Columbus nozzle," and the effect of the disintegration of the broken stone in the sprinklers and the causes thereof will be considered. This is important, as great care was exercised in the selection of the stone. The discussion should also include an explanation of the increase in the number of bacteria in the settling basins.

It is agreeable to note the change in the appearance of the Scioto River since the installation of the sewage disposal plant. Within the city limits, and even below the disposal plant, it is now a comparatively clean and attractive stream, whereas, prior to the construction of the intercepting sewers and the disposal works, it was foul and disagreeable.

While engineers are interested in knowing why the plant at Columbus is not bearing out the results predicted by its designers, it is an open question whether the State's interests are any better subserved by demanding a higher degree of bacterial efficiency, even if a water supply was taken from the Scioto within a comparatively short distance from the disposal works. It is safe to assume that sooner or

Mr. Potter. later public sentiment will demand the filtration of all public water supplies, and, in cases where a river is reasonably free from gross sewage pollution, a filter will protect the water supply.

There are many cases where a supply is drawn from a grossly polluted source and a filter is producing therefrom a satisfactory water supply. This is notably the case at Chester, Pa. The speaker, however, does not wish to go on record as endorsing the Chester conditions as ideal. It will be remembered that the water supply is taken from the Delaware River about 10 or 15 miles below the point where the City of Philadelphia pours its unpurified sewage into it. Besides Philadelphia, all the cities on the Schuylkill and Delaware Rivers, with the exception of Reading, at present drain their unpurified sewage into these rivers. The filter records at Chester show that the plant is successfully eliminating as high a percentage of bacteria as most of the mechanical filters throughout the United States. The speaker believes that the experience at Chester amply justifies the opinion that a clarification process of sewage disposal is all that is required in most cases. Such a process has the further advantage that, under American conditions, as they exist to-day and are likely to exist for many years, it is possible of attainment, whereas, if it be assumed as true that sanitary conditions require the complete or nearly complete purification of the sewage, engineers are doomed to failure, and will thus be held up to ridicule.

Mr. Fowler. GILBERT FOWLER, ESQ.* (by letter).—There is little doubt, that, softening and clarification of the raw water being necessary, the adoption of pressure filters with arrangements for automatic cleansing is the best method that could have been devised to meet the situation. Like all filtration systems, however, it requires constant and vigilant attention, especially when, as in this case, the operations of softening, clarification, settlement, and filtration have to be regulated simultaneously. The results obtained, from the point of view of the removal of *B. Coli,* are highly satisfactory; and as far as it is possible to analyze the occasional failures, they appear to arise, in some cases at any rate, during or after periods of heavy rainfall, when the bacterial content of the river water seems to be greatly increased. Unfortunately, this difficulty is inherent in all filtration schemes where the source of supply is subject to intermittent pollution, and especial vigilance is then necessary. At such times, although the river water may be actually more dilute in respect to organic impurity, the rate of filtration should be diminished rather than increased.

The apparent occasional growth of organisms in the filtered or settled water is significant rather as an indication of imperfect removal of organic matter which may serve as pabulum for these and other growths, than as directly affecting the hygienic quality of the

* Consulting Chemist, Manchester, England.

Mr. Fowler.

water. This, of course, will depend more on the species of bacteria present than on their number, and it is noticeable that while in some cases as many as 2 000 organisms may be present per cubic centimeter of filtered water, *B. Coli* is not found in 50 cu. cm. of the same sample.

In view of these facts the experiment should be tried of operating one of the filters as a sprinkling filter, on the same lines as the sewage filters afterward described. No alteration in construction would be required except the provision of spray jets, and plenty of head appears to be available for their operation. Experiments by Miquel, Mouchet, and others, in France, have shown the great diminution which takes place, both in the organic matter present and in the number of organisms, when the filters are operated in this manner, *B. Coli* being completely eliminated. The dependence of the number of organisms of other sorts on the organic pabulum present was shown by treating the filters with a solution of peptone, when an enormous increase took place in the organisms present in the filtered water.

One obvious advantage in conducting water-works filters in this manner is that the bacterial purification does not depend entirely on the efficiency of the filter as a mechanical strainer. With every type of filter operated under head there is always danger of what may be described as leakage, especially at the junction of the filtering medium and the containing walls of the filter; the advantage of the spray is that the filter pressure is practically *nil*.

The subject is still in the experimental stage, but there is reason to think that water-works filters of the ordinary type may give place, under certain conditions, to spray filters.

As the general design of the sewage purification works is the outcome of long-continued and careful experimental study, there is little to offer in the way of criticism. The construction costs for the purification works appear to be on much the same scale as for similar works in England. The operating charges should be low except in the unfortunate event of the backing up of the river water into the filters, referred to by the author. Without knowing more of the size and character of the river, it is difficult to express an opinion as to the possibility of discharging into it accumulations of sludge from the septic tanks and settling basins. If it were possible to store the sludge in the tanks during the dry weather and to discharge it into the river only during periods of heavy flow, as the writer believes was originally contemplated, there is no *a priori* objection to such a course, if it is carried out with judgment. Experiments have shown the possibility of discharging sludge from septic tanks into a tidal estuary without nuisance, if care is taken to perform the operation at times when a dilution exceeding a defined minimum is assured.

The situation at Columbus would appear to be more difficult, as the dry hot weather, when the river may be presumed to be at its

Mr. Fowler.

lowest, is just the time when fermentation is likely to be most active in the tanks, with a consequent tendency for excessive quantities of suspended solids to pass on to the filters and an increased likelihood of nuisance from spray jets. That something of the kind has been apprehended already is evident from a study of the figures for suspended matter in the septic tank effluent. In May and in August these figures were becoming excessive, and the tanks were accordingly cleaned out during these months. It is of interest to note that while the first effect of sprinkling filters is to reduce the suspended matter in the effluent, the tendency afterward is for it to be greater in the filter effluent than in the tank effluent. This is in accordance with general experience, and is satisfactory from the point of view of the self-cleansing action and consequent permanence of the sprinkling filters. It is further in accordance with experience that the suspended matter in the filter effluent should increase markedly in the spring or early summer months, owing to the increased activity of organic life in the filters at this time as compared with the previous colder season; this phenomenon has been termed by certain workers in England, "the spring flush out." For all these reasons, it might be wise to make arrangements for the eventual treatment of sludge on land.

Turning to the more purely chemical results from the filters, what is noticeable, from an English point of view, is the comparatively low percentage of purification effected, which, even after the settling tanks, seldom reaches 50 per cent. The nitrate figures also are lower than is generally the case from similar filters in England. At the same time, of course, it is obvious that the sewage is very dilute, judged by European standards, and the rate of filtration exceedingly high. The main and most important effect of the filters is to saturate the effluent with dissolved oxygen.

The analytical figures under this head are for the most part very satisfactory, and it is this, doubtless, which accounts for the general non-putrescibility of the effluent; it may also be remarked that a 24-hour incubation test is not a very severe one.

The purification effected by the works may be quite adequate for the conditions which have to be met, and after all this is the true criterion of a successful works.

It would be of great interest if systematic observations could be made of the state of the river above and below the works at different periods of the year, as there would then be material for forming an opinion as to the efficiency of the method used, both for the disposal of sludge and for the purification of the effluent.

In conclusion, the writer would like to express his admiration for the complete and business-like manner in which all the details are presented in Mr. Gregory's paper. It is only by such publications that real progress is achieved.

Mr. Taylor.

WILLIAM GAVIN TAYLOR, M. AM. SOC. C. E.—In this paper, which covers the detailed construction of two noteworthy public works, sanitary engineers have a most valuable contribution to the literature of the art. The successful solution of the many difficult problems besetting the design of both projects is clearly shown by the several tables of operation. Rarely do sanitary engineers have prepared for their benefit a monograph describing work so rich in quality of design, and so full in excellency of detail. The exhaustive presentation of the unit costs of the work, arranged under proper subject grouping, is, in itself, of very great value.

The studies and designs for the Columbus Sewage Purification Works were executed during 1905. In an analytical examination of the detailed construction of these works, the date of execution and the state of the art at that time should be clearly borne in mind. This sewage plant represents the beginning of percolating-filter construction in the United States, and its engineers were required, in a large measure, to design the works under conditions of greater severity than had before been met. For guidance in these matters there existed two important sources of experience: First, a few years of English experimentation and study on small plants; and secondly, the results attained at the Columbus Sewage Testing Station, built and operated for a year for this specific purpose. The English sewages thus studied, however, and the English climatic and other controlling conditions, were very different from those governing the possible operation of sewage works in Central Ohio.

A close study of these percolating filters, of large area, during the year of their operation, with the noting of all normal and abnormal characteristics, is a most valuable guide to future design. Local conditions frequently develop features of unusual practical importance in the operation of sewage filters, as was well illustrated by the development of a fungus on the surface of the percolating filters at the Waterbury Sewage Experiment Station during 1906. The suspended matter applied to the percolating filters in the influent spray did not show any tendency to produce surface clogging, but on the surface of each filter a fungus mass grew continually, and, if allowed sufficient time, would spread over and cover the surface stones with a blanket-like mat so dense as to effect a surface clogging and cause the applied sewage to gather in pools on the surface. Two weeks of continuous operation of the percolating filters, without a period of rest, was sufficient time for the development of a luxuriant growth of the saprophytic plant over the entire surface, so compact as to destroy almost completely the aeration so essential to filters of this type.

The control and subjection of this cryptogam were matters of vast importance, and were vital to the efficient operation of the filters. Soon after the test percolating filters were placed in service it was

Mr. Taylor.

noticed that a gray and almost transparent gelatinous coating appeared on the surface of the stones, which developed into a thick, spongy, filamentous mass. So rapid was the development of this saprophytic growth that often at the end of a week each stone was covered by a mass having a thickness from $\frac{1}{16}$ to $\frac{1}{4}$ in. If the blanket-like mass was allowed further development, it would continue to grow in thickness, causing pooling and cessation of aeration, to the detriment of the oxidizing and nitrifying processes active within the filter.

Observations proved that the fungus could be easily dried and reduced to the thickness of tissue paper by resting the filter and giving the surface full exposure to the direct rays of the sun. On drying, the filamentous growth became very brittle, breaking up into small particles which desquamated from the filter stones. The particles thus scaling off were carried away from the bed by the effluent when the filter was again put in service. Exposure for one day to normal sun proved to be sufficient to reduce the fungus when it was about $\frac{1}{8}$ in. thick, while two days' exposure was sufficient to cause the desquamation of the heavier growths. Cyclic operation of the filters proved to be desirable, and, as a result of many tests, the filters were dosed continuously for five successive days and then allowed a complete rest for two days. Under this mode of operation the effluents were well oxidized and non-putrescible, and the fungus growths were sufficiently restrained.

Stormy and cloudy weather conditions especially favored these surface growths, a season particularly favorable occurring during the latter part of December, 1905, and the first week of January, 1906.

The study of the fungus under various modes of dosing developed two facts: First, that operation of the filters at double rate during the 12 hours of daylight and resting them during the 12 hours of darkness favored a luxuriant growth; and second, that a double-rate dosing at night followed by a complete rest and desiccation in the sun through the day was sufficient to prevent such growth.

In its early development the slimy mass presented a grayish appearance; after a few days many bright-colored spots appeared over the mass, varying in tint from a salmon pink to a darker red and sometimes even to almost jet black. The reddish color was shown by analysis to be due to the iron.

The interest of Mr. Leo. F. Rettger, Assistant Professor of Bacteriology at Yale University, led him to study the morphology of the organism and its development in various culture media. After a very thorough and long-continued washing of portions of the fibrous mass, he found that an isolation and satisfactory cultures of the mould could be obtained in acid-sugar gelatine. The composition of the most successful medium was as follows: Water, 1 liter; gold label gelatine (acid), 120 grammes (12%); dextrose or lactose, 30 grammes (3%).

Mr. Taylor.

The natural acidity of the gelatine, which was sufficient to turn litmus paper decidedly red, was left unchanged. As the bacterial colonies developed but slowly in the acid gelatine, pure transplantations could be readily made. While the absolute identity of the particular organism causing the obstruction on the filters was not determined, it was found to have a close resemblance to *Monillia* in many particulars.

As far as the speaker is aware, corresponding growths have not occurred on any of the municipal percolating filters now in operation, but it is understood that growths of somewhat similar nature have been found on the experimental sewage filters at Philadelphia.

Mr. Hazen.

ALLEN HAZEN, M. AM. SOC. C. E.—It is very gratifying that these purification works have been carried out so fully and completely.

Fifteen years ago the speaker was called to Columbus to examine a project for increasing the city's ground-water supply, which was then inadequate. He found that there was no good reason for thinking that sufficient additional ground-water could be secured for a permanent supply, and suggested that it would be better to look to the Scioto River. As the low-water flow would clearly be insufficient to meet increasing demands, he suggested the examination of the valley for a site for an impounding reservoir. He also suggested the purification of the water by filtration, and also, with some hesitation, because of the novelty of the proposal, that the water should be softened. He has not yet had the pleasure of seeing this plant, and it is difficult to study out all the details, even from so excellent a description as the author has given.

There is one point on general design in which the speaker is interested, and it is mentioned in the hope of bringing out the designer's idea, that is, as to the relative elevations of the filters and the pure-water reservoir. At the Little Falls plant of the East Jersey Water Company,* the filters were built over the pure-water reservoir. This was desirable and, perhaps, necessary, because the site was limited in area. No objection was made to it, because Weston controllers were used, and, according to the practice of the time, these were set about 10 ft. below the water on the filters. They were incapable of acting when submerged, and, therefore, the highest level in the pure-water reservoir was, necessarily, at least 10 ft. below the flow-line of the filters.

Since that time filters have been repeatedly built over pure-water reservoirs where there were no limiting conditions of area, and where, as in this case, other types of controllers, capable of operating when submerged, were adopted.

At Columbus the flow-line of the pure-water reservoir is 10 ft. below that of the filters, and the reservoir is 15 ft. deep. In other words, the loss of head from the filters to the pure-water reservoir, with the

* *Transactions*, Am. Soc. C. E., Vol. L, p. 394.

Mr. Hazen.

full utilization of the capacity of the latter, will range from 10 to 25 ft. In plants with which the speaker has been connected, most of the filtering work is done with heads not exceeding 5 or 6 ft. With controllers capable of acting when submerged, the flow lines of pure-water reservoirs have been placed 2 or 3 ft. below those of the filters, with the idea that their ordinary water levels would be 6 or 8 ft. below the flow-lines of the filters.

There are two principal reasons for keeping up the elevation of the pure-water reservoir:

1.—Head is saved, and head is always valuable in water-works operation;

2.—The operation of the plant is more convenient and satisfactory.

Regulating devices which act when submerged, serve to limit the rate within the quantities for which they are set, and allow the water to back up on the filters, thereby reducing the rate when the delivery is greater than the need. There is some fluctuation in the rate of the filters under this system, but it takes place very gradually and only within the limits for which the controllers are set. There is no reason to think that such fluctuations in rate are injurious to the filters in any way.

On the other hand, with the pure-water reservoir a considerable distance below the filters, there is a tendency to keep it always full, as far as possible, and when it is kept full, the filters are made to fluctuate in rate to correspond with the use of the water. This fluctuation in rate may be brought about artificially by the attendants, or naturally by submerging the controllers, according to the type of apparatus.

Probably the fluctuations in rate are fully as great in the long run as they are with the reservoir at a higher level. The speaker has seen plants in which the pure-water reservoir remained full, year in and year out, and where all the fluctuations were met directly by the filters, so that, for purposes of operation, there might just as well have been no pure-water reservoir.

In this case there may have been other reasons than those which appear for placing the pure-water reservoir so much lower than the filters, and these remarks, therefore, should be considered, not as a criticism of this particular plant, but as a discussion on this feature of purification plants in general.

Mr. W. B. Fuller.

WILLIAM B. FULLER, M. AM. SOC. C. E.—This paper treats essentially of the construction work of a well-studied and carefully-designed plant, and should be highly commended for its logical arrangement, clear statements of facts, and intelligent presentation of the subject. The speaker has been particularly interested in this record of accomplished work, as he was identified with some of the prelim-

Mr. W. B. Fuller.

inary reports which led to its accomplishment. In his discussion, Mr. Hazen has touched on one phase of this work which seems to be a necessary part of all large municipal construction work, that is the long time elapsing between the inception of the project and its completion. As the author has stated, the first steps toward this improvement were taken in 1897, twelve years ago. In 1900, as Assistant to Samuel Gray, M. Am. Soc. C. E., the speaker investigated the matter of the storage reservoir and of the purification of the water supply very thoroughly, but no active construction was begun until four years later. Similarly, as Assistant to Rudolph Hering, M. Am. Soc. C. E., he had the pleasure of examining the sewerage question, but this also met the same fate, and the propitious moment for construction did not come until three years later.

Turning to a consideration of the construction features, the speaker would first call attention to the profile of the dam. There are very few dams, in the United States at least, which can show such a large factor of safety under rigid analysis of stresses as this one, and, as the speaker is very conservative on this point, and believes that many large dams carry far too small a factor of safety, it is a pleasure to call attention to this feature of the Scioto Dam. In how many dams does the line of pressure lie within the middle third, when allowance is made for excessive ice pressure and a large upward pressure on the bottom of the dam?

The author states that inasmuch as the water was to be purified by filtration, it was not considered necessary to strip the reservoir, inferring that it might have been thought necessary under other conditions. The speaker believes that conditions could not exist which would render necessary the stripping of a reservoir fed by a silt-bearing stream such as the Scioto. Indeed, to him the greatest defect in the entire Columbus improvement, as built, is the failure to provide means for keeping the entire body of water in the reservoir from becoming highly turbid after each storm, and thus requiring the use of much larger quantities of chemicals for clarification purposes than would otherwise be necessary.

It is noted that the pumping station is operated by steam, and it would be interesting to know the considerations which led to the adoption of steam, as most of the preliminary reports were in favor of utilizing the surplus water power at the dam by converting it into electricity, or, more economically still, by compressed air, utilizing the direct fall of the water.

It is noted that the Water Purification Works are not only for water filtration, but for water softening, and this, together with the newness of the science of water softening as applied to large municipal plants with such a varying quality of water as that furnished by the Scioto, sufficiently accounts for the exceedingly complicated design of the works. It is a question, however, whether simplicity

Mr. W. B. Fuller.

of construction is not more to be desired than arrangements which are expected to meet every conceivable condition.

The author is to be commended for his careful analysis of costs, as given in Tables 10 and 14, which adds greatly to the value of the paper as a record and as a guide in the construction of similar works. Engineers, as a rule, fail to give any information about costs, therefore these tables are all the more noticeable.

Mr. Kuichling.

E. KUICHLING, M. AM. SOC. C. E.—The author is to be congratulated on having presented a clear description of one of the most important sanitary works in the United States. The plant for softening the hard water of the Scioto River is the largest that has ever been constructed, and the sprinkling filter plant for oxidizing the effluent from the sewage sedimentation tanks is likewise the most extensive of its kind. The plans, as well as the results attained, therefore, are apt to be scrutinized very closely by all who are interested in such subjects.

As the works were not completed until late in 1908, and as comparative analyses of the crude and purified liquids are available for only eight months of regular operation, January-August, 1909, it is probably too soon to criticize the results achieved. A much better judgment of the efficiency of the processes and plants can be formed after those in charge have had ample time to become more familiar therewith, and also to learn all the local peculiarities of the river and sewage. From the data submitted, however, the results appear to be very satisfactory, and a substantial improvement may be expected.

It is fair to state at the outset that the designers of the Water Purification Plant had very little time to study the character of the river water, and hence the success attained demonstrates their great skill in this art. For the sewage works, on the other hand, the results of the exhaustive preliminary studies and experiments made at Columbus in 1904-05 by George A. Johnson, Assoc. M. Am. Soc. C. E., were at hand, thus affording an excellent foundation for the preparation of the plans, as well as a means of estimating their practical performance. The speaker will accordingly confine his remarks to a brief consideration of the results attained by the process selected for purifying the sewage.

On arriving from the city, the sewage is thoroughly sedimented in large open concrete tanks having a capacity of about 8 000 000 gal., after having been screened at the main pumping station through two sets of gratings with bars 1.0 and 0.5 in. apart in the clear, respectively. It is then sprayed upon beds of broken limestone having an average depth of 5.33 ft., the lower 10 in. being composed of stones from 3 to 4 in. in size, and the remainder of stones ranging from 1 to 3 in. in size. An aggregate area of 10 acres of such beds was provided for dealing with a maximum flow of 20 000 000 gal. per day, the intention being to apply the liquid at the rate of 2 000 000 gal. per acre per day. The effluent from these sprinkling filters is then allowed to settle for

about 2 hours in a pair of shallow open basins before being discharged into the river. Mr. Kuichling.

Table 16 shows that the daily quantity of sewage pumped and treated has ranged from 1 760 000 to 21 400 000 gal., with an average of 12 400 000 gal., and has been applied to sprinkling filter areas in service ranging from 0.42 to 6.20 acres, the average being 3.10 acres. According to these figures, it would seem that, on the average, 4 000 000 gal. of tank effluent have been applied per day to an area of 1.0 acre of sprinkling filter, instead of 2 000 000 gal. per acre per day, as contemplated. The highest rate of filtration given in Table 16 is 5 400 000 gal. per acre per day on July 7th and August 16th, 1909.

Such high rates of filtration may be explained perhaps by leaving out of account the period of time each day that the filter is not in service. Thus, if 2 000 000 gal. of liquid were applied to 1 acre uniformly during only 12 hours, and this acre of surface were then allowed to rest for the remaining 12 hours of the same day, the rate of application would be 4 000 000 gal. per acre in 24 hours, although in reality only half this quantity passed through the filter in the course of a single day. There may possibly be a distinction between "rate of application" and the phrase "rate of filtration on millions of gallons per acre per day" used in Table 16; if so, it should be clearly explained, since the headings of the columns relating to this matter, namely, "Volume filtered, in millions of gallons per day," "Filter area in service, in acres," and "Average rate of filtration, in millions of gallons per acre per day," certainly lead the reader to infer that the stated volumes of liquid were actually applied to and passed through the stated filter areas in the course of the stated days.

If this inference is correct, twice as much tank effluent has been applied per day, on the average, to portions of the filter beds as was originally proposed, notwithstanding that plenty of area was apparently available during the greater part of the time for the lower rate of filtration; and, therefore, it may be asked why the contemplated rate was doubled. On the other hand, if the said inference is wrong, the speaker believes that the phraseology of the indicated column headings of Table 16 requires some modification.

A further examination of this table, under the headings of "Oxygen Consumed by the Screened Sewage," "Septic effluent," and "Filter effluent," allows an approximate estimate to be made of the average degree of purification attained by the action of the sedimentation or septic tanks and the sprinkling filters during the six months, March to August, 1909, as follows:

| | Parts per million. | Differences. | Equivalent percentage of purification. |
|---|---|---|---|
| Oxygen consumed by screened sewage | 44.1 | .... | .... |
| " " " septic effluent | 26.3 | 17.8 | 40.3 |
| " " " filter effluent | 17.1 | 9.2 | 35.0 |
| | | 27.0 | 61.2 |

Mr. Kuichling.

On this basis of estimating the improvement in the quality of the effluent, these averages would be highly significant if little variation occurred in the figures from day to day, or month to month, but such is far from being the case. On many days the oxygen consumed was greater for both septic effluent and filter effluent than for the screened sewage, but this anomaly is due to the impossibility of tracing the course of any particular volume of sewage through the plant. Taking the averages for each of the said six months, the following will be found:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Maximum | improvement | of | screened | sewage | by | tank, | 54.4% | in April; |
| Minimum | " | " | " | " | " | " | 23.7% | " July; |
| Maximum | " | " | tank | effluent | by | filter, | 45.9% | " June; |
| Minimum | " | " | " | " | " | " | 5.3% | " May; |
| Maximum | " | " | screened | sewage | by | both, | 71.9% | " April; |
| Minimum | " | " | " | " | " | " | 47.3% | " July. |

It would also be interesting to learn why the filters caused so large an improvement of the tank effluent in June, and so little in May.

The improvement in the quality of the effluent cannot be estimated by the quantity of suspended matter removed, as it happens that during the majority of the months for which data are given, the quantity of suspended matter in the filter effluent was somewhat greater than in that of the septic tanks. The greatest improvement in this respect, however, by the tanks alone, was 77.1% in June, and the least was 35.6% in July, the average for the whole period of eight months being 58.8 per cent. As to the relative proportions of organic (or volatile) and mineral (or fixed) substance in this suspended matter, no figures are submitted.

In regard to the number of bacteria per cubic centimeter, it may be remarked that, in the screened sewage, it ranged from 9 000 000 to 150 000, with an average of 1 820 000; in the septic tank effluent, from 6 450 000 to 40 000, with an average of 770 000; and, in the filter effluent, from 5 300 000 to 20 000, with an average of 510 000. After the turbid filter effluent had been allowed to settle for 2 hours, the number of bacteria generally increased, so that the average was but little less than that for the tank effluent.

To facilitate the study of the analytical data relating to the treatment of the sewage, that are contained in Table 16 and occupy eight pages of the paper, the speaker has prepared a condensation thereof showing the maximum, minimum, and average figures for each month, and also for the entire period of eight months. This condensation is submitted as Table 69, in the hope that it will be found convenient by others.

The figures in Table 69, together with those in Table 16, show very plainly that the final effluent from this large plant is not potable water, and even that its non-putrescibility is not always well established.

Mr. Kuichling.

TABLE 69.—GIVING IN CONDENSED FORM THE RESULTS OF CHEMICAL AND BACTERIAL ANALYSES OF SEWAGE EFFLUENTS PRODUCED AT COLUMBUS, OHIO, DURING EIGHT MONTHS, JANUARY–AUGUST, 1909.

| Max., Min., or Ave. | Month, 1909. | Temperature of sewage, in degrees Fahrenheit. | Volume filtered, in million gallons per day. | Filter area in service, in acres. | Average rate of filtration, in million gallons per acre per day. | Chemical Analyses, Parts per Million. | | | | | | | | | | | | Bacteria. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Suspended matter. | | | | Oxygen consumed. | | | | Settling-basin effluent. | | | | Millions per c. c. | | | |
| | | | | | | Screened sewage. | Septic effluent. | Filter effluent. | Settling-basin effluent. | Screened sewage. | Septic effluent. | Filter effluent. | Settling-basin effluent. | Chlorine. | Dissolved oxygen. | Putrescibility, 24 hrs. @ 37° C. | Nitrites. | Nitrates. | Screened sewage. | Septic effluent. | Filter effluent. | Settling-basin effluent |
| Max... | Jan..... | 56 | 18.65 | 4.60 | 4.98 | 1 088 | 169 | 84* | 81 | 192 | 72 | ..... | 43 | .... | 9.2 | P | 0.60 | 1.17 | 5.92 | 2.30 | 2.52 | 1.96 |
| Min ... | " ..... | 51 | 6.29 | 2.50 | 3.40 | 109 | 77 | 74* | 28 | 45 | 41 | ..... | 18 | .... | 1.3 | " | 0.04 | 0.27 | 1.10 | 0.22 | 0.24 | 0.30 |
| Ave ... | " ..... | 55 | 11.80 | 3.10 | 3.90 | 340 | 105 | 81* | 50 | 100 | 60 | ..... | 30 | .... | 4.6 | " | 0.20 | 0.65 | 2.70 | 0.90 | 0.80 | 0.80 |
| Max... | Feb..... | 55 | 21.4† | 6.2† | 4.7† | 814 | 230 | ..... | 81† | 100 | 62 | ..... | 29† | .... | 10.6† | P & N | 0.86 | 7.20 | 3.0 | 0.80 | 0.75 | 0.90 |
| Min ... | " ..... | 44 | 5.2† | 2.5 | 3.25 | 58 | 70 | ..... | 32† | 7 | 13 | ..... | 17† | .... | 5.2† | " + | 0.05 | 0.10 | 0.03 | 0.05 | 0.16 | 0.24 |
| Ave ... | " ..... | 50 | 13.8† | 4.1† | 3.9† | 285 | 120 | ..... | 65† | 53 | 35 | ..... | 23† | .... | 8.0† | " + | 0.54† | 2.14† | 0.95 | 0.35 | 0.35† | 0.45* |
| Max... | Mar..... | 55 | 20.1 | 4.9 | 5.14 | 378 | 156 | 82 | 67 | 74 | 43 | 28 | 21 | .... | 11.7 | " | 1.20 | 11.34 | 2.92 | 1.52 | 1.07 | 0.89 |
| Min ... | " ..... | 51 | 4.35 | 2.5 | 2.6 | 68 | 60 | 26 | 27* | 11 | 12 | 9 | 12* | .... | 6.2 | " | 0.29 | 0.76 | 0.15 | 0.04 | 0.03 | 0.24* |
| Ave ... | " ..... | 53 | 16.1 | 3.98 | 4.12 | 178 | 87 | 47 | 39* | 43 | 28 | 17 | 16* | .... | 9.7 | " | 0.80 | 4.20 | 1.18 | 0.55 | 0.43 | 0.50* |
| Max... | April..... | 61 | 16.85 | 4.48 | 4.45 | 604 | 140 | 116 | 48 | 99 | 36 | 25 | 18 | .... | 11.5 | " | 1.15 | 7.00 | 5.0 | 1.42 | 5.30 | 1.92 |
| Min ... | " ..... | 51 | 4.29 | 2.13 | 2.40 | 54 | 42 | 22 | 9 | 14 | 14 | 10 | 8 | .... | 0.6 | " | 0.23 | 0.67 | 0.2 | 0.04 | 0.11 | 0.11 |
| Ave ... | " ..... | 56 | 11.47 | 3.13 | 3.8 | 209 | 78 | 59 | 26 | 57 | 26 | 16 | 14 | .... | 6.2 | " | 0.57 | 2.08 | 1.57 | 0.74 | 0.90 | 0.71 |
| Max... | May..... | 63 | 17.92 | 4.43 | 4.50 | 566 | 300 | 740 | 33 | 64 | 30 | 45 | 17 | 218 | 10.9 | " | 1.20 | 8.1 | 6.80 | 6.45 | 2.55 | 1.44 |
| Min ... | " ..... | 53 | 1.76 | 0.42 | 3.30 | 13 | 12 | 14 | 15† | 8 | 7 | 10 | 9† | 15 | 3.6† | " | 0.42† | 1.2† | 0.25 | 0.10 | 0.18† | 0.14† |
| Ave ... | " ..... | 58 | 12.18 | 3.07 | 4.03 | 200 | 78 | 118 | 24† | 38 | 19 | 18 | 13† | 52 | 7.6† | " | 0.70† | 2.93† | 2.20 | 1.30 | 0.80† | 1.00† |
| Max... | June..... | 71 | 16.9 | 3.75 | 4.8 | 366 | 101 | 148 | ..... | 74 | 40 | 19 | ..... | 64 | 9.0 | " + | 0.94 | 4.65 | 9.00 | 2.63 | 1.02 | .... |
| Min ... | " ..... | 63 | 10.4 | 2.50 | 3.75 | 96† | 31† | 21† | ..... | 16 | 13 | 9† | ..... | 20† | 5.8 | " † | 0.41* | 1.40† | 0.72 | 0.57 | 0.19 | .... |
| Ave ... | " ..... | 67 | 13.4 | 3.1 | 4.3 | 214† | 49† | 56† | ..... | 46 | 24 | 13† | ..... | 49† | 7.3 | " † | .....* | .....* | 3.65 | 1.29 | 0.52 | .... |
| Max... | July..... | 70 | 15.8 | 3.55 | 5.4 | 198 | 114 | 259 | ..... | 67 | 47 | 51.0 | ..... | 76 | 8.0 | " | ..... | 4.40 | 5.77 | 1.12 | 0.41 | .... |
| Min ... | " ..... | 63 | 5.0 | 1.40 | 3.0 | 52† | 18† | 32† | ..... | 19 | 14 | 11.4† | ..... | 28† | 5.4 | " | ..... | 1.85† | 0.36† | 0.25 | 0.06 | .... |
| Ave ... | " ..... | 67 | 10.42 | 2.40 | 4.36 | 115† | 74† | 91† | ..... | 38 | 29 | 20.1† | ..... | 47† | 6.8 | " | ..... | 3.43† | 1.35† | 0.54 | 0.17 | .... |
| Max... | Aug ..... | 72 | 13.2 | 2.80 | 5.4 | 305 | 118 | 213 | 25 | 70 | 45 | 24.9 | 20 | 59 | 8.4 | N | ..... | 6.18 | 2.20 | 0.88 | 0.28 | 0.55 |
| Min ... | " ..... | 68 | 8.56 | 1.67 | 4.0 | 61† | 31† | 17† | 10* | 17 | 13 | 11.2† | 15* | 10† | 4.7† | " | ..... | 2.00† | 0.16 | 0.10 | 0.02 | 0.08* |
| Ave ... | " ..... | 69 | 9.82 | 2.13 | 4.5 | 126† | 55† | 75† | 20* | 42.5 | 32 | 18.3† | 18* | 44† | 6.4† | " | ..... | 3.70† | 0.93 | 0.46 | 0.12 | 0.36* |
| Max ... | Entire Period | 72 | 21.4 | 6.2 | 5.4 | 1 088 | 300 | 740 | 81 | 192 | 72 | 51 | 43 | 218 | 11.7 | N | 1.20 | 11.34 | 9.00 | 6.45 | 5.30 | 1.96 |
| Min ... | | 44 | 1.76 | 0.42 | 2.6 | 13 | 12 | 14 | 9 | 7 | 7 | 9 | 8 | 10 | 0.6 | P | 0.04 | 0.10 | 0.15 | 0.04 | 0.02 | 0.08 |
| Ave ... | | 60 | 12.4 | 3.10 | 4.11 | 208 | 85 | 74 | 41 | 52 | 32 | 17 | 20 | 48 | 7.1 | P & N | 0.56 | 2.73 | 1.82 | 0.77 | 0.51 | 0.75 |

*Very few figures given. †Data incomplete.

Mr. Kuichling. The degree of purification attained, however, appears to be abundantly ample to prevent the river from becoming offensive during its low stages, and there was no intention of accomplishing much more than this. The statement is often found in popular scientific literature that the effluent from such sprinkling filter beds is always clear, pure, and sparkling; but as this is rarely the case when real sewage is treated, the publication of the results actually attained on a large scale by this finely-designed and well-managed plant, will assist materially in correcting popular fallacies concerning sewage purification, and hence this paper is an extremely welcome and valuable addition to the literature of true sanitary engineering.

Mr. Pearse. LANGDON PEARSE, ASSOC. M. AM. SOC. C. E. (by letter).—The work at Columbus is noteworthy for the thoroughness and completeness with which a comparatively novel field was entered.

In the design of the Sewage Purification Works, the writer will discuss the underdrain tile, and the importance of bedding the feet in the floor while the concrete is still green. The tile come whole, and, when split, do not necessarily give an even bearing on all six feet. In planning the construction of the Experimental Testing Station for the Sanitary District of Chicago, the writer had some tests made by R. W. Hunt and Company, to determine the carrying capacity of the tile with the feet simply resting on a soft pine board, also when bedded in a quick-setting mixture of cement and plaster of Paris. The results were interesting.

The tile were 6 in. in diameter. The load was distributed over 2 in. of the crown. The first crack appeared at 750 lb. per running foot, and failure at 1 250 lb. per running foot in one case, and at 930 lb. per running foot, and failure at 1 300 lb. in another. With the feet bedded in $\frac{1}{2}$ in. of cement, the first crack occurred at 1 320 lb. per running foot and failure at 1 855 lb. per running foot.

Mr. E. A. Kemmler, the Resident Engineer at Columbus, reported a test of two tiles, each 24 in. long, bedded in a concrete floor when soft, as in the filters. After five days a cement sack was placed on each tile for a cushion, and a platform, loaded with bricks, was placed on top. Both tiles broke at 7 500 lb., or at 3 750 lb. for each tile, that is, at 1 875 lb. per running foot of tile.

The nozzle at Columbus is one of the earliest developed, and has a large orifice. From time to time, the writer has experimented with the nozzles at Columbus and other places, and has found that almost any orifice will clog, if fungus be present in the supply pipes as luxuriantly as it is at the Chicago Testing Station. The weak part of the Columbus nozzles is the arm. A careless attendant can easily kick or twist the arms out of true. This likelihood of derangement, however, is true of practically all the nozzles on the market, even of those of the spindle type, for an uneven strain at the root of the thread may put any of the

spindles out of true. A variable head is probably desirable with most nozzles, unless they are specially designed. The writer does not favor the splasher type of distributor, owing to the exposed overhead distributors with the likelihood of freezing and the complication of adjustments. Mr. Pearse.

The writer has been much interested in the working results of the Sewage Purification plant, and the good showing made during the second winter of operation. This should prove conclusively that open sprinkling filters can be operated successfully in a northern climate. At Chicago, the writer has been experimenting with a closed sprinkling filter, to determine whether a roof will help in the operation. An unforeseen result has occurred—the rapid and luxuriant growth of a fungus which bridges over even the spaces between 1½- to 3-in. crushed limestone, and causes marked clogging. The growth of this fungus is favored by darkness, moisture, and oxygen, all of which conditions are present in the covered filter.

The question of the sand-catcher, brought up by Mr. Griggs, is very pertinent in view of the lack of uniformity in such matters. At the 39th Street Sewage Pumping Station of the City of Chicago, which is fed by an intercepting sewer, 16 ft. in diameter, much heavy suspended matter, such as chunks of septic sludge from back sewers, sand, etc., is swept down at times of storm. It is the custom of the city employees to pump down the screen chamber (about 20 ft. wide, by 30 ft. long), once every two months, and draw all the settled matter into one of the pumps, forcing it into Bubbly Creek. It has to be dredged from there by the Sanitary District. This is certainly a crude method of sand removal, but it shows the need of an adequate design for sand-catchers.

In connection with the operation of the filter plant at the Water Purification Works, the writer will be much interested in following the working of the sand. At a recent meeting of the Illinois Water Supply Association, some very interesting facts were presented, establishing the growth in size of the sand grains, where iron and lime are used as coagulants, due to the incrustation of lime. Whether similar growth will occur in connection with this softening process remains to be seen.

RUDOLPH HERING, M. AM. SOC. C. E. (by letter).—In discussing this paper the writer wishes first to emphasize the author's reference to Julian Griggs, M. Am. Soc. C. E., as the one to whose judgment and persistence both the City of Columbus and the country owe these works. The writer's connection with them at an early date permits him to testify to the sincerity and faithfulness with which Mr. Griggs attacked his problem, and to the single aim which he maintained throughout to get the best possible solution. Mr. Hering.

Secondly, the writer wishes to commend the skillful and equally sincere and faithful manner in which the two works have been exe-

Mr. Hering.

cuted by the author. The many novel features and details that it was necessary to work out required the acquisition of much knowledge, persistence, and systematic labor. Mr. Gregory deserves high credit for the manner in which he attacked and pursued the problem and completed the works which now stand among the best of their kind in the United States.

The following discussion, limited to the improved sewage works, is intended to point out that they could be but a step in a rapidly advancing art, which fact it is necessary to recognize in order to form a fair and just opinion of them as they now stand.

The author's historical account records the first recommendation made for sewage treatment in 1898 by Messrs. Julian Griggs and John W. Alvord, to the effect that the sewage should be screened and then doubly filtered through beds of coke at a net rate of 500 000 gal. per acre per day.

Three years later, the writer, taking advantage both of the positive and negative results of experience gained in the interval, recommended septic tanks for preliminary treatment, to be followed by intermittent filtration through sand instead of by the double coke filters. This change was proposed because it had become evident in Europe that in a short time the coke filters would clog and cause expensive and repeated cleaning or replacing. It had also become evident that sand filters could be operated at much greater than the usual rates, if the sewage were first freed from the bulk of its suspended matter; and for this purpose the frequent use of septic tanks, particularly in England, had indicated quite a general preference. Nevertheless, it was cautiously suggested by the writer that only a small portion of the proposed Columbus works should be built at first and operated for one year, before any extensions were made, so as to derive in the meantime all possible aid from actual experience in the locality.

Two and one-half years more elapsed before the matter was again taken up, and in view of further advances made in the art, it was then properly concluded to make an extended experimental investigation before undertaking the final design of the works. The latter recommendation was made near the close of 1903, when English experience was beginning to point strongly toward the economy and efficiency of the sprinkling method.

The Columbus experiments verified the hope that even in a cold winter climate this method could be used, and on account of its economy it was finally adopted. As experience had been insufficient in America, further English precedent was adopted, as far as practicable, namely, the use of septic tanks, followed by sprinkling filters and finally by settling basins.

The Columbus works were designed in 1905 and based upon what was then recognized as the best practice. During the five years

between that time and the present, experience with such plants in Europe and in several plants in America, including Columbus, has been extensive. A glance at this experience reveals a number of improvements over the Columbus design, which point to the attainment of still better results. While the Columbus plant, the first of the large important ones in America, is practically fulfilling its promises, it has furnished, together with other plants, valuable data for still further improvements in the future. It is the writer's intention to point out some of the directions in which such better results may be secured. Mr. Hering.

*I.—The Septic Tank.*—The Columbus tanks are doing practically what was expected of them when designed. The septic treatment, however, as such, has not fulfilled all early expectations, one of which was a material reduction in the sludge deposited from the sewage, the disposal of which was generally considered the *bête noire* of all sewage treatment. As regards the reduction of sludge, the actual results have been disappointing. In many cities it has been but slightly greater than that obtained by fresh sewage settling basins, and the stench from septic tanks has often been quite an objectionable feature.

The septic state being one where oxidation is displaced by putrefaction, very foul odors, due to the resulting hydrogen compounds, are allowed to escape. Fresh sewage, when containing a sufficient amount of oxygen, has very little odor, and, therefore, where practicable, it is decidedly better to handle it in that condition.

At the present time most efforts are being made in the direction of keeping the sewage as fresh as possible, both where it is to be subjected to bacterial treatment on land and where it is to be oxidized in flowing water.

The reduction of sludge is not only a question of putrefaction, it is also and largely one of water content. Sludge containing 90% of water has one-half the bulk of the same sludge if this contains 95% of water. Therefore, means of reducing the water content are at present viewed with more favor than reduction by septic means, although the latter still retains a proper value.

The arrangements of Messrs. Birch, then Travis and Imhoff, which, in two-story tanks under cover, permit of a gravity separation of the suspended matter from the fresh sewage, are coming into favor; so that fresh instead of septic sewage can flow through the upper tank, while the suspended matter settles into the lower tank to form the sludge, and to remain in it until all putrescible matter is converted into non-putrescible matter, and can then at frequent intervals be withdrawn in small quantities. The almost continuous motion and overturning given the particles of sludge by these frequent withdrawals, sufficiently rearranges their position so that a continuous

Mr. Hering.

anaerobic action can be maintained throughout. As a matter of fact, the rotting of the sludge in these tanks under these conditions is at least as complete as in the older form of septic tank, where sewage passes over the sludge and constantly supplies it with fresh bacteria.

Of such tanks the latest are the Emscher tanks in Germany, suggested by Dr. Imhoff, from which the sludge issues after several months' retention, with but 75% to 85% of water, is well digested, friable instead of sticky, and has no putrescent odor. It flows into under-drained lagoons, where in a few days it dries to 70% and less of moisture, so that it can be spaded, removed, and dumped for permanent deposit.

There must be considered in this direction, also, a question which was formerly too little emphasized, namely, that the different parts of suspended matter have various degrees of resistance to putrefaction. Some animal matter is highly putrescent, while some, like bones, hair, and tendons, is quite resistant. Some vegetable matter, particularly that of rapid growth, speedily putrefies, while hardwood fiber may resist for years. Recent experiments in Germany by Dunbar and others have shown the different periods of time required. From these and similar facts useful data may be gathered regarding the best means of sludge treatment.

A more efficient method of removing suspended matter than usually supposed is fine screening. Experiments have shown that in fresh sewage, not too far from the origin, it is possible with moving screens to remove one-third and perhaps one-half of the suspended matter. The nearer the origin, the greater the amount. One advantage of this removal is that the matter screened out is fresh and when dried can more easily be destroyed by fire—the most sanitary mode of destruction—than when it is in the form of sludge. Another advantage is that the smaller quantity of solid matter retained in the sewage reduces not only the amount of final sludge to be handled, but also the amount of solid matter which must be finally oxidized, and to which purpose a certain capacity of the works must be devoted. There are still other troubles that early and fine screening may reduce. Where, in one case, a fine screen was temporarily out of order and only a coarse screen remained, the change in the character of the sewage was marked by a noticeable increase in the stoppages of the sprinkling nozzles, even after the passage of the liquid through an ordinary septic tank.

The writer believes that in most cases it will be found advantageous to have fine screening done between a settling basin and the oxidizing beds, which will give the latter a greater efficiency and prevent, upon the bacterial surfaces, an undue accumulation of solid matter which must later be unloaded. In Salford a roughing filter is advantageously inserted for this purpose. A fine screen used just before an oxidizing bed acts similarly to the sand layer over a Dunbar coarse filter, though not as efficiently.

Mr. Hering.

It is evident that the less the quantity of suspended matter retained in the sewage when spread upon the oxidizing beds, the more efficient these will be, the less stone or bacterial surface will be required, and the less unloading will take place. From a sand filter there is no unloading at all because the suspended matter is all retained, no matter what the velocity of percolation or its changes may be, which changes are the chief cause of the unloading of coarse-grained filters.

*II.—Sprinkling Filters.*—There is first the difference between fixed and movable jets. Although the fixed nozzle has been continually improved, has the advantage of greater simplicity of construction and operation, and is specially advantageous for weak sewage, the movable sprinkler is generally preferred in Europe, because, as a rule, it distributes sewage more evenly and, therefore, gives a better utilization of the stone medium for oxidation. On the other hand, there are disadvantages, particularly in America, besides greater cost, due partly to necessarily greater attention and partly to the much colder winters. Excepting in our Southern cities, filters with movable sprinklers would have to be housed. As these have not yet been used on a large scale in America, practical experience has not yet indicated definitely the degree of preference measured in cost.

A study of the relative efficiency of various European coarse-grained filters to oxidize sewage, has indicated the importance of considering what the writer has termed the bacterial surface of a filter receiving liquid sewage. English efficiencies are generally given for the cubic yard of medium, and it is found that with the same preparatory treatment of similar sewages, and the same time for percolation and aeration, a cubic yard of material will increase oxidation in proportion to the area of the bacterial surface available. The fact that the surfaces of the grains upon which the bacteria are active double in area for grains of half the diameter, is a partial explanation of the high purification obtained on beds with small stones, and in fact with sand grains. When it is realized that the capillaries and air cells in the lungs of an adult man have a surface of nearly 1 000 sq. ft. upon which, by diffusion through the thin membranes, the venous blood is converted into arterial blood by taking in oxygen from the inhaled air, it is easy to understand the value of a large bacterial surface for a sewage oxidizing filter.

The writer has elsewhere elaborated these facts, and has suggested the possibility of determining more rationally than heretofore the number of square feet of bacterial surface required to oxidize to any desired degree the sewage contributed from the average individual.

This required bacterial surface allows the necessary average diameter of the grains to be obtained when the depth of the bed is given.

The depth of a bed is determined by the length of time of percolation required to get the necessary oxidation for the desired degree of purification. The time is dependent on the character of the sewage;

Mr. Hering.

if it is weak and there is less suspended matter, the necessary time will be less, up to a certain limit, and therefore also the depth of bed. A filter with large stones, where sewage percolates more rapidly, must be deeper than one with small stones, other things being equal, if it is to give the same degree of purification.

What has seemed to the writer to be a more important factor in sewage oxidation than has usually been admitted, is the aeration of a filter.

Observations in America and Europe, and discussions with competent authorities, have convinced him that this subject has not yet been exploited sufficiently, and that the efficiency of some of our works could be increased materially by allowing a freer circulation of air through the interstices of the filters.

It is true that the vacuum caused by bacterial activity in extracting oxygen, to form combinations which are removed as solutions in the effluent, is filled by the air drawn into the filter, and that in this manner the lost oxygen is naturally replenished; but it is also true that there is then always present an active force and sufficient in strength, in one direction, to more than equal the frictional resistance of drawing the air into the filter, and in the other, to rarefy correspondingly the air within the filter and reduce the amount of oxygen available for the bacteria in the film.

Under similar conditions, similar effects are seen in higher animals requiring oxygen. In a rarefied atmosphere breathing becomes more active to secure the necessary amount of oxygen, and all physical exercise becomes more difficult. In compressed air, on the other hand, breathing is less active because less necessary, and exercise is less difficult than in normal air. The different physiological results of living in poorly ventilated rooms or out of doors are well known, although there may be but a small difference in the quantity of oxygen.

This rarefying force caused by bacterial activity, and which was measured as a vacuum by Dunbar, has, therefore, a constant tendency to reduce bacterial energy, however slight the reduction may be, and reduces correspondingly both growth and reproduction and, therefore, in the same measure, activity and oxidation.

By establishing reverse conditions reverse results should be expected. If, instead of a vacuum, a plenum is established, the conditions are changed. There is more air in the filter than the normal, and a greater amount of oxygen. There is no draft upon bacterial energy, but an air pressure more than sufficient to overcome the frictional resistance, and a surplus of one of the elements which produce the energy. This surplus will induce growth and reproduction correspondingly and continuously and, therefore, oxidation, provided always that another and main source of energy, namely, a sufficient quantity of oxidizable matter is also present.

Mr. Hering.

Therefore, it has been the writer's opinion for some years that some means should be established to utilize the natural motion of the air above a filter as a force to impel air into its interstices, whether upward from the drains below or downward from the surface above does not change the general conclusion, so that there will be a tendency to maintain a plenum within the filter to encourage bacterial growth rather than a vacuum to discourage it.

Examinations of filters in Europe and America, where this matter could at all be judged, have supported this conclusion rather than otherwise.

It has been said that the descending water would draw fresh air into the filter as fast as it was required to supply the lack of oxygen. This is true, but it does not in the least prevent the vacuum which is produced within the slimy bacterial film from receiving air only by absorption. Further, if the atmosphere is colder than the interior of the filter, the warmer interior air, instead of descending with the descending water, would ascend and move in the opposite direction from that of the water.

Also, the fact that some sewage filter effluents show a fairly good saturation with oxygen does not imply that no vacuum exists within the bacterial film where oxidation is taking place.

The European circular block filter, elevated above the ground, permits of the wind blowing against a cylindrical surface, and tends to produce a plenum for a certain distance within it. It has been said that no draft of air is noticed within such filters, and that practically, therefore, no circulation existed except near the outside surface against which the wind was blowing. The laws of aerodynamics will easily indicate wherein this conclusion is correct and incorrect. Briefly, it cannot be expected that there will be a noticeable horizontal current very far into the body, because of the friction, nor can it be expected to move with equal velocity or direction through the interstices of every part of a vertical cylinder in which the resistance increases with every foot from side to side both horizontally and vertically. No doubt, however, a block filter of usual size, standing above the ground will have a better aeration than one sunk below the ground.

If the filters are sunk into the ground, a plenum can be obtained by hoods automatically turned toward the wind by vanes. The air can be discharged into the drains to force it upward through the filter. Or, in a climate requiring covered filters, it can be discharged in the space beneath the roof and allow of an escape downward through the drains.

The quantity of air sufficient to establish this plenum and penetrate the films is small, as but a slight excess is required over the quantity withdrawn by oxidation in the filter. There is, of course, no objectionable result from a larger quantity of air passing through the bed.

Mr. Hering. There would be no benefit derived in the way of oxidation after all the bacterial surfaces are supplied, but there may be a great benefit in preventing algæ growths. Dunbar found that good aeration with a plenum prevented algæ growths which occurred near the surface of filters and tended to clog them.

As a slight atmospheric movement will furnish the plenum, the necessary quantity of air introduced in the winter of middle latitudes in the United States should not lower seriously the temperature within the filter.

*III.—Final Settling Basins.*—The object of the basins receiving the effluents from sprinkling filters is to allow of the settling of the suspended matter which had passed through the filters when they were unloading. In other words, when the rate of dosing is accelerated and the suspended matter adhering to the grains has lost its glutinous consistency by oxidation, and is therefore more easily detached and generally found non-putrescent, such matter is washed through the filter, makes the effluent turbid, but deposits easily. Therefore, to give the effluent a better appearance and not to produce turbidity in the small watercourses into which in England such effluents are usually discharged, English engineers have generally added final settling basins to their works.

When sewage has its suspended matter well separated from the liquid before it reaches a filter, when the aeration of the filter is sufficient to prevent growths within it, and when the filter is sufficiently well proportioned to allow of the necessary degree of oxidation to prevent any further putrefaction, then there will be much less, if any, cause for final settling basins, and their expense can often be avoided. Where, finally, the effluent can be discharged into a river, such as rivers in the South, which almost always carry large amounts of suspended matter, then the addition of a much smaller number of parts per million of suspended non-putrescent solids is quite legitimate. Where, in fact, the river is capable at certain times of receiving the sludge itself, as the best means of disposing of it, it does not now seem necessary in such cases to have a final settling basin.

Therefore, and again particularly in streams in the South, their expense may be saved and much better applied, in the writer's opinion, to increase the facilities for preventing fine suspended matter from reaching the oxidation beds and to establish a greater factor of safety in those parts of the work where it is most needed.

As a final treatment, where pathogenic bacteria should be excluded from a watercourse, nothing at present appears to be more effective than a sterilization of the effluent by the addition of a small quantity of hypochlorite of lime solution, as used for some years by certain German cities at the sewage outfalls on their large rivers, and as now proposed for several American cities.

Mr. Hering.

To obtain the greatest efficiency and economy for this treatment, it is necessary to have as little suspended organic matter in the sewage as possible. Separating tanks, such as the Emscher tanks, may in many cases alone be sufficient for this purpose where, as in the Emscher district, the effluent can be given an ample dilution, and where an additional oxidation of the liquid by a passage through filters is not necessary.

Mr. Johnson.

GEORGE A. JOHNSON, ASSOC. M. AM. SOC. C. E. (by letter).—Mr. Gregory's excellent paper is very complete in all its details as to design and construction. There is still much to be said, however, about the practical operation of these works, a feature which could not well be covered exhaustively by the author at the time his paper was written. Although preliminary tests and studies of the water-softening problem at Columbus were made under the writer's direction, his particular attention was given to a study of the sewage question, and it is to this portion of the paper that he proposes to limit his discussion.

The water-softening and filtration works have already made a record to be proud of, and the widespread satisfaction of the citizens of Columbus over the quality of the water they are now getting, and the greatly diminished death rate from typhoid fever in the city, are sufficient proofs of the fulfillment by these works of the purposes for which they were intended.

The sewage problem was worked out with particular care and deliberation, full advantage being taken of the results of preliminary tests conducted by the city for the purpose of ascertaining the most suitable and economical method of purification to meet local requirements.

The stream flow of the Scioto River is extremely low at times, and, on this account, a fairly clear and non-putrescible effluent is required. In any process of sewage purification which will effect this result, a large percentage of the sewage bacteria will be removed as a matter of course. More complete bacterial purification than that which would be effected in septic tanks, sprinkling filters, and their subsidiary settling basins, was not deemed necessary, for it is 200 miles by river to the first important water-works intake—that of the City of Cincinnati. More than this, a part of the sewerage system of Columbus is built on the combined plan, and, even now, considerable sewage in its crude state escapes into the river through the storm overflows after heavy rains. Consequently, any apprehension of danger which may be held to be attached to the possible presence of disease germs in the sewage or sewage effluent entering the river at Columbus, will presumably be directed more particularly to the sewage escaping from the storm overflows than to the effluent of the purification works.

Pathogenic bacteria not only do not multiply in sewage, but die out with great rapidity in such an environment. The classic researches of Messrs. Jordan, Russell, and Zeit, on the longevity of the typhoid

Mr. Johnson.

germ in the Chicago Drainage Canal, furnish the best direct evidence on this point. It appears, therefore, to be plain that there must be a high mortality among such pathogenic bacteria as the crude sewage may contain, during their passage through the various parts of the purification works, particularly in the septic tanks.

There is considerable diversity of opinion among engineers and public sanitarians as to the quality of work which sewage purification works should do as to meeting local requirements. The idealist hopes for complete purification of sewage, when discharged into large rivers, even carrying the purification beyond the point of obtaining a clear and non-putrescible effluent, into the field of sterilization. There are extreme cases where such a degree of purification may be necessary, and it always may be desirable, but the benefit derived from such treatment must be very great to justify the effort and the cost. At Columbus, the local conditions did not appear to require such complete bacterial purification, the problem being essentially one of eliminating nuisances in the immediate vicinity of the city, rather than effecting a degree of purification from the standpoint of the pollution of the water supplies of nearby cities.

Up to the time of the Columbus experiments there was considerable speculation among engineers as to whether a sprinkling filter, with the sewage distributed in a fine spray over the surface of the bed, could be operated efficiently during the cold winter months. It is gratifying to note that, during the year 1909, no more trouble was encountered in the operation of the main works at Columbus than was met with during the preliminary investigations. The distribution of sewage over the surface of the stone appears to be interfered with but little by the formation of ice on the bed, and it is probable that this fact would hold true in considerably colder climates than that at Columbus.

On making a careful study of the results of the practical operation of the Columbus Sewage Works for the year 1909, it is particularly gratifying, to the writer at least, to observe that they are in all respects an almost complete confirmation of the beliefs which were largely founded on the results of the preliminary investigations made at Columbus in 1904-05 under his direction.

The septic tanks have proven fully as efficient as was expected in the removal of suspended matter, averaging 60% for the entire year. During the month of July, the percentage removal was low, due, largely, to the abnormally small amount of suspended matter in the raw sewage, but the character of the septic tank effluent during this month, as regards its content of suspended matter, was as satisfactory as usual. The bacterial removal by the septic tanks followed closely that of the suspended matter, averaging 57% for the entire year.

Many septic tanks have shown at times higher numbers of bac-

Mr. Johnson.

teria in the effluent than in the crude sewage, due to bacterial propagation in the tanks, but it by no means follows that the species of bacteria which so propagate are pathogenic. Rather is the reverse true, for, as before stated, it appears to be a well-established fact that disease-producing germs will not multiply in water or sewage, and that such bacteria as do multiply under such conditions are harmless forms.

The removal of "oxygen consumed" by the septic tanks and by the entire system, averaging 39 and 70%, respectively, for the year 1909, are results thoroughly in keeping with those accomplished by other sewage works of this type elsewhere.

The sprinkling filters have not shown themselves to be efficient in the removal of suspended matter, nor was it intended or expected that they would be. The sprinkling filter is not a filter in the sense that it permanently retains suspended matters, but may more properly be termed a biological machine whereby crude organic matters, temporarily retained in the bed, are modified so that they are reduced to a state of practical mineralization. The sprinkling filter depends for its economical and efficient operation on the now well-recognized phenomenon of being capable of periodically storing and unloading suspended matters, such action being so well balanced that a long period of years elapses during which the filter may be kept in continuous operation and not become clogged and inefficient.

As before stated, it is decidedly not the purpose of a sprinkling filter to remove and permanently retain suspended matter, and a glance at Table 70 will show that during the year 1909, the amount of suspended matter in the septic sewage applied to the filter, and in the filter effluent, was almost exactly the same, a feature demanded of any efficient filter of this type, namely, that the pores therein may not become clogged and so prevent the free circulation of air throughout the bed. Furthermore, it must be borne in mind that the suspended matter which is discharged by the sprinkling filter is not crude organic matter, such as is found in the applied sewage, but matter which has been reduced practically to humus and is, therefore, subject to slight possibility of further break-down.

During 1909 the final settling basins reduced the suspended matter in the filter effluent to the lowest practicable limit, the average amount found in the effluent of these basins being 36 parts per million for the entire year. This result confirms the statement made by the writer,* in which it was pointed out that:

"Speaking generally, it appears that the Columbus sewage ordinarily contains in the neighborhood of 50 parts per million of suspended matter which can be removed by subsidence only in part and with great difficulty in practice."

* "Report on Sewage Purification at Columbus, Ohio," p. 39.

TABLE 70.—MONTHLY SUMMARY OF RESULTS OF ANALYSIS OF SCREENED, SEPTIC, AND FILTERED SEWAGE AT THE COLUMBUS SEWAGE PURIFICATION WORKS.

| Month, 1909. | Average rate of filtration, in million gallons per acre daily. | Parts per Million. | | | | | | | | Bacteria per Cubic Centimeter (Millions). | | | Percentage Removal. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Suspended matter. | | | | Oxygen consumed. | | | | | | | Suspended matter. | | Oxygen consumed. | | Bacteria. | |
| | | Screened sewage. | Septic effluent. | Filter effluent. | Settling-basin effluent. | Screened sewage. | Septic effluent. | Filter effluent. | Settling-basin effluent. | Screened sewage. | Septic effluent. | Filter effluent. | By septic tank. | By whole system. | By septic tank. | By whole system. | By septic tank. | By septic tank and filter. |
| Jan..... | 3.90 | 340 | 105 | 81 | 50 | 100 | 60 | ..... | 30 | 2.70 | 0.90 | 0.80 | 69 | 85 | 40 | 70 | 67 | 70 |
| Feb..... | 3.90 | 285 | 120 | ..... | 65 | 53 | 35 | ..... | 23 | 0.95 | 0.35 | 0.35 | 58 | 77 | 34 | 57 | 63 | 63 |
| Mar..... | 4.12 | 178 | 87 | 47 | 39 | 43 | 28 | 17 | 16 | 1.18 | 0.55 | 0.43 | 51 | 78 | 35 | 63 | 53 | 64 |
| Apr..... | 3.80 | 209 | 78 | 59 | 26 | 57 | 26 | 16 | 14 | 1.57 | 0.74 | 0.90 | 63 | 88 | 54 | 75 | 53 | 43 |
| May ..... | 4.03 | 200 | 78 | 118 | 24 | 38 | 19 | 18 | 13 | 2.20 | 1.30 | 0.80 | 61 | 88 | 50 | 66 | 41 | 64 |
| June..... | 4.30 | 214 | 49 | 56 | * | 46 | 24 | 13 | ..... | 3.65 | 1.29 | 0.52 | 77 | 74 | 48 | 72 | 65 | 86 |
| July..... | 4.36 | 115 | 74 | 91 | * | 38 | 29 | 20 | ..... | 1.35 | 0.54 | 0.17 | 37 | 21 | 24 | 47 | 60 | 88 |
| Aug..... | 4.50 | 126 | 55 | 75 | 20 | 43 | 32 | 18 | 18 | 0.93 | 0.46 | 0.115 | 56 | 84 | 26 | 58 | 51 | 88 |
| Sept..... | 3.52 | 170 | 64 | 62 | 26 | 69 | 44 | 24 | 16 | 1.93 | 1.27 | 0.46 | 62 | 85 | 36 | 77 | 34 | 76 |
| Oct..... | 3.13 | 141 | 63 | 72 | 28 | 64 | 45 | 25 | 16 | 4.17 | 2.26 | 1.02 | 55 | 80 | 30 | 75 | 46 | 75 |
| Nov..... | 3.14 | 235 | 117 | 137 | 48 | 65 | 44 | 29 | 18 | 5.09 | 1.50 | 0.73 | 50 | 80 | 32 | 72 | 71 | 86 |
| Dec..... | 3.74 | 191 | 86 | 121 | ..... | 119 | 62 | 25 | ..... | 2.98 | 1.19 | 0.47 | 55 | ..... | 48 | 79 | 60 | 84 |
| | 3.87 | 200 | 81 | 83 | 36 | 61 | 37 | 20 | 18 | 2.40 | 1.03 | 0.56 | 60 | 82 | 39 | 70 | 57 | 77 |

*Out of service on account of construction of retaining walls.

Mr. Johnson.

Mr. Johnson.

The bacterial removal by the Columbus plant as a whole, as indicated by the results of analysis for 1909, was not so complete as had been anticipated, averaging 77 per cent. In connection with this feature consideration must be given to the thought before referred to, relating to the propagation of harmless forms of bacterial life during the purification process. The sprinkling filter itself teems with harmless bacterial life, without which its efficiency as an oxidizing machine would cease, so that, while the analyses indicate a certain removal of bacteria, it will be understood that many of the bacteria contained in the final effluent were doubtless propagated by harmless germs during the process of purification.

With a thorough knowledge of the behavior of the Columbus Sewage Works since they were first put into operation, it is gratifying to the writer to be in a position to express the opinion that from a constructional standpoint the city has a plant of which it may well be proud; and that from a practical standpoint the works, in all departments, have proven efficient in the performance of the duties required of them. Mr. Gregory and his associates are deserving of high praise for the character of the work they have done; and, for the eminently successful performance of both the water and sewage works since they were put into operation, much credit is due W. R. Copeland, Assoc. Am. Soc. C. E., Chief Chemist of the Water-Softening and Purification Works, and Mr. C. B. Hoover, Chief Chemist of the Sewage Purification Works.

Mr. G. W. Fuller.

GEORGE W. FULLER, M. AM. SOC. C. E. (by letter).—The author has recorded, in an admirable manner and with great thoroughness, the design and construction of the new works at Columbus. These works mark, in several ways, a new epoch in the history of municipal engineering, because of the novelty associated with the treatment of several aspects of the local problems. Reference is made, of course, to the softening features of the new water-works, and to the design of the first large plant of the sprinkling filter type for the treatment of sewage along lines which have progressed so rapidly during the past decade.

The preliminary work done at Columbus, preparatory to designing the practical works, was undertaken with rather more than ordinary thoroughness, due to the foresight of Julian Griggs, M. Am. Soc. C. E., who was City Engineer for some years, and to whom great credit is due for the successful manner in which he guided the execution of such extensive improvements in works for both water and sewage, for a single city, at the same time. In some measure the garbage disposal works should also be mentioned as a part of Mr. Griggs' far-reaching programme, although these works are scarcely completed at this time.

Mr. G. W. Fuller.

## Water Purification Works.

The clarified, decolorized, and softened Scioto River water, of good quality hygienically, has given excellent satisfaction to the citizens of Columbus. The difference in quality of the water before and after treatment shows a greater range, both in work accomplished and also in variation of the degree of treatment effected along the several lines, than at any other plant for the treatment of water with which the writer is acquainted.

To appreciate this, attention is called to the range in the different constituents of the river water, as given in Table 71.

TABLE 71.—Showing Range, in Parts per Million, of Constituents of Scioto River Water.

| Date. | Color. | Turbidity. | Total hardness. | Alkalinity. | Incrustants. | Magnesium. |
|---|---|---|---|---|---|---|
| Feb. 13, 1909..... | 17 | 22 | 409 | 209 | 200 | 40 |
| " 15, 1909..... | 40 | 86 | 356 | 150 | 206 | 25 |
| " 17, 1909..... | 70 | 431 | 167 | 75 | 92 | 14 |
| " 24, 1909..... | 100 | 1 311 | 94 | 56 | 38 | 9 |
| Mar. 1, 1909..... | 80 | 188 | 155 | 79 | 76 | 12 |
| " 8, 1909..... | 45 | 52 | 259 | 119 | 140 | 19 |
| June 5, 1909..... | 45 | 46 | 269 | 170 | 99 | 18 |
| " 6, 1909..... | 75 | 254 | 206 | 135 | 71 | 17 |
| " 7, 1909..... | 87 | 283 | 116 | 96 | 20 | 12 |

Briefly stated, the Scioto River water is treated with chemicals in the manner and for the purposes as follows:

1.—Lime-water or a weak suspension of quicklime is added to the river water to combine with the free and half-bound carbonic acid, and thus reduce the alkalinity, or temporary hardness, or bi-carbonate alkalinity, well toward a limit where there will be substantially no more carbonate of lime and magnesia in the water than is naturally soluble in the absence of carbonic acid. This limit varies with the temperature and other factors, but is roughly from 30 to 40 parts per million.

2.—Lime is also added in quantities in excess of that required for the purpose just stated, that is, for combining with magnesia so as to cause a substantial portion of the magnesia to separate out as a gelatinous flocculent precipitate. This precipitate is available, and actually serves, as a coagulant, in removing turbidity and other constituents in a manner similar to aluminum hydrate or iron hydrate.

3.—A coagulant is added at times, in fact for the greater portion of the year, so as to flocculate suspended matters and dissolved color coming from vegetable matter in a manner more or less similar to that ordinarily followed in preparing water for mechanical filters elsewhere and in the absence of any softening operations.

4.—Soda is added to reduce the incrustant or permanent hardness or sulphate hardness. Mr. G. W. Fuller.

Bearing these statements in mind, attention is again called to Table 71, wherein is shown a wide variation, occurring indeed with very rapid fluctuations at different hours of the same day, with respect to the quantity of color, turbidity, and hardness, present in the river water, and the varying amount of magnesium which can be utilized for the purposes of coagulation. Associated with these conditions is a further fact that as a result of the softening process there is some turbidity, due to granular carbonate of lime, appearing in the settling basins. Taking together the character of the water and the variations in the amount of chemicals to be added as a result of the inter-reactions during treatment, especially as to the effect of magnesia and turbidity due to carbonate of lime, it will take the operators of filter plants but a moment to appreciate that the Columbus plant is more difficult to operate than any other water-treating plant now in service. Hence, in the writer's opinion, the results accomplished by Mr. Copeland call for substantial praise for his alertness and fidelity to his task in learning the individuality of the local water and, at the same time, in maintaining the city's supply in a condition which is rarely open to criticism.

The difficulty in operating the Columbus Water Purification Works on some occasions, especially after heavy rains, is probably greater than is appreciated by any one who has not spent considerable time at Columbus, and who has not observed the rapid fluctuation in quality of the water in the Scioto River hour by hour at different seasons of the year, and with different combinations and fluctuations seldom occurring twice alike. The reason of the difficulty is to be found in the rapid adjustments to be made in the required quantities of chemicals, due in part to the changes in the character of the river water, and in part to the inter-reactions taking place in the water undergoing treatment. The former can be reckoned with, but the latter are puzzling.

The writer's discussion will relate principally to differences in behavior between what was expected with the knowledge available at the time the plant was designed,* and that which has been experienced in practical operations.

*Filters.*—The mechanical filters used at Columbus are quite similar on the whole to those designed and built for the Hackensack Water Company, at New Milford, N. J. There are some differences as regards rate controllers and minor devices, as well as in the arrangement of the strainer system. The only feature which the writer desires to discuss relates to the effect on the sand bed and strainer system of the lime, which, to some extent, remains in the water after sedimentation and prior to filtration. It was expected that this lime

* See article giving outline of features considered in the design of this plant in *Engineering Record*, Vol. 53, p. 202.

Mr. G. W. Fuller.

would adhere to, and, to some extent, stick together the sand grains which might require some special cleaning treatment from time to time. Practice has proved the correctness of this, although it is too early yet to state how frequently the sand layer will have to be given some special treatment in order to overcome the effect of the accumulation of lime on the sand grains. Speaking generally, the deposit, after a year and a half of service, is not of great significance; and it seems fair to state that whatever cost is necessary for the cleaning of sand, due to the effect of lime, it will not be great, and that the use of a mechanical filter in the final treatment of water undergoing softening is a practical success.

*Settling Basins.*—The settling basins have behaved substantially as was expected, and there is no novel feature with respect to them, other than the opportunity provided for their use in parallel or in series, and of withdrawing the water after it has passed through only a portion of the settling basins, with the idea of having it in suitable condition for filtration without the application of coagulants.

*Coagulation.*—The use of a coagulant in conjunction with the softening process has extended to a somewhat greater period throughout an ordinary year than was expected. This is partly due to the water being rather more turbid than was expected after coming from the Scioto River Storage Reservoir; partly to the inability to precipitate as much of the magnesium in the form of the gelatinous hydrate as was expected; and partly and, perhaps principally, to a secondary turbidity developing in the settling basins and caused, apparently, by the slow settling out of the granular carbonate of lime which results from the softening treatment.

*Application of Raw Water.*—As regards the use of facilities for applying raw water for correcting caustic alkalinity, due to faulty application of lime, at times when the river water is rapidly fluctuating, it should be stated that at such times this arrangement is used with much satisfaction. Generally speaking, it does not seem to be necessary to make use of that procedure as a regular feature in the operation of the plant.

*Application of Chemicals.*—This portion of the plant contains a number of very excellent features. There are also several features about the Columbus design which are capable of improvement, and have been improved in designs elsewhere, prepared since the Columbus works were put under contract in June, 1905. The use of lime-water as distinguished from a weak suspension of lime did not work out satisfactorily, although with some minor changes lime-water could doubtless have been secured and used as intended. The very thoroughly baffled reaction or mixing chamber has proven successful and ample. It eliminates some of the disadvantages due to deposits of lime, which were expected to be associated with the use of lime sus-

pensions. The use of solutions or suspensions of the various chemicals of known strength is, of course, in accordance with the earlier plants at Little Falls, New Milford, and elsewhere. The method is doubtless capable of giving excellent results when well handled, although it is true that the local stirring arrangements were not fully adequate. Mr. G. W. Fuller.

*Chemical Feed Regulator.*—As regards automatic control of the volume of chemical solutions so that the application will be in proportion to the flow of river water entering the plant, it is the writer's belief that the idea is an excellent one, and that the devices designed at Columbus afford a reasonable procedure to that end. There is no doubt that the chemicals received at Columbus, and applied to the water, have proved much more bothersome than was anticipated. This has been due in part to the chemicals being of a much poorer quality that was expected. Thus it was hoped, as regards quicklime, that there would be no difficulty in securing a grade with something like 95% of available lime. A product having this purity, however, has not been found. As to sulphate of iron and sulphate of alumina, these products, as used at Columbus, seem to have been much more corrosive than the ordinary grades elsewhere. In fact, six or eight months of service at the Columbus plant, as regards the coagulant layout, seems to have produced more effect as to wear and tear than did six or eight years of service at the plant at Little Falls, N. J.

*Soda Tanks.*—The effect of soda on concrete was not understood at the time the Columbus plant was designed and, from the limited experience available, it was not expected that the masonry would be attacked to the extent which has occurred.

*"Tuning-Up."*—Speaking generally, the devices for the application of chemicals at the Columbus works are capable of doing good and efficient service with the ordinary grades of chemicals. With some additional care, the same is true with the chemicals which were actually used during the first few months of operation. It is likewise true that there are quite a number of little things which can and should be improved, and which ordinarily come under what is called the "tuning-up" process of a plant containing such a wide range in devices as the one in question. The Columbus plant has not been "tuned-up" as promptly or as thoroughly as has been the case with similar plants elsewhere. This has been due to several reasons; among which may be mentioned the question of availability of funds at the time when the plant first went into service, although the sum involved was merely nominal when expressed in percentages of the total cost; and also to uncertainty as to how the "tuning-up" could be carried out most satisfactorily to meet all the requirements of the river water in its variations throughout the year.

*Degree of Softness.*—It is planned to reduce the total hardness of the water, as sent to the city, to about 90 or 100 parts per million.

Mr. G. W. Fuller.

There have been a few occasions when the hardness of the softened water has been 120 parts or so, and this usually produced some unfavorable comment, particularly if it occurred on "wash day." Such an amount of hardness was practically without exception the result of mishaps, and certainly can be avoided at all seasons of the year with this plant. Cold weather, of course, slows up the reactions and it would be difficult to get at all times a total hardness of the softened water of about 75 parts per million, although for the warm seasons of the year this is perfectly feasible. As the waters of Lake Michigan and Lake Erie contain from 120 to 140 parts of total hardness and seem to satisfy the water consumers in the various lake cities, it is a question in the writer's mind if it is worth while for people in the Middle West, accustomed to hard water, to go to the expense of softening water to less than 120 parts, which is about the point where the Columbus water consumers begin to complain of hardness.

*Bacterial Results.*—From a hygienic standpoint, the bacteria of an objectionable nature have unquestionably been removed with substantial thoroughness. This is demonstrated by the very gratifying reduction in the prevalence of typhoid fever in Columbus since the plant went into service. It is true that growths of certain harmless species of water bacteria have occurred in the settling basins at times, but experience at various places in the United States and Europe shows that such growths are not related to disease-producing germs. The writer has seen more or less similar growths in a dozen different places, including plants with both types of filters, beginning with the experimental filters at the Lawrence Experiment Station of the Massachusetts State Board of Health, in the summer of 1892. The practicability of hypochlorite of lime for purposes of sterilization was, of course, unknown when the Columbus filters were designed. The development of practical knowledge of water sterilization constitutes one of the most important steps in advance during the last few years, and its use at Columbus is fitting at a plant which does so much toward the improvement of the local river water.

*Corrosion.*—As far as the writer has been able to learn, the filtered water at Columbus is rather less corrosive as to iron than ordinary filtered water or ground-water. This is due, of course, to the substantial absence of free and half-bound carbonic acid. The water will rust iron surfaces, of course, which is true of all waters well supplied with dissolved atmospheric oxygen. The water has produced some effect on galvanized parts of meters, and it is unquestionably true that waters containing mono-carbonate alkalinity and caustic alkalinity have added powers for dissolving zinc. The mono-carbonate alkalinity is characteristic of the water of practically all cities where lime and sulphate of iron are used in the coagulation of the water supply. Caustic alkalinity has appeared to quite a noticeable degree on a few

Mr. G. W. Fuller.

occasions, and is practically due in every instance to some mishap in the application of lime. It is the writer's belief that the operation of the plant is now sufficiently in hand so that caustic alkalinity need not appear, although he doubts if any real objection can be made to a water which contains a slight trace, say, up to a limit of about 5 parts per million.

### Sewage Purification Works.

As others of the staff of consulting engineers will discuss the Sewage Works, the writer will confine himself to a very few comments in this regard. He desires to point out, however, that the plant is giving a result which, in his opinion, reasonably meets the requirements of the local conditions.

The increase in size of the stone in the sprinkling filter is doubtless an advantage when due regard is given to the cost of maintenance. It is a fact, however, that the material is considerably coarser than that used in the test filters studied under Mr. Johnson's direction. The size and depth of material in the sprinkling filters of the main works at Columbus seem hardly capable of giving as good an effluent as was obtained from the better experimental filters, under the conditions of dosing originally designed for the main works. The difficulty seems to be in too high a rate of sewage flow through certain limited areas. Beginning with the summer of 1909, this was corrected in part by hand regulation of the sluice-gates in the main gate-house. This will soon be corrected with permanent appliances, the delay having been occasioned by the lack of electric power which will soon be available from the the new garbage reduction plant now nearing completion in the immediate vicinity of the sprinkling filter plant.

When the sprinkling filter is unloading its stored material, and at times of very low water, it has seemed desirable to use the final settling basins, but, on other occasions, it has been the writer's advice to by-pass them.

As to the septic tanks, the process of bacterial destruction of suspended matter has been rather more active in the large works than in the small tanks studied at the testing station. The septic sludge has very little odor indeed, and more nearly resembles the septic sludge at Birmingham, England, than that at any other place in this country with which the writer is familiar.

The ebullition of gas in the septic tanks is more intense than is usually noted, and there has been more odor on some occasions from the septic tanks and spray jets than was considered desirable. As far as known, the odor has never been noticeable more than 300 yards distant. It was considered advisable, however, to use alternately the different compartments of the septic tanks, and the shorter detention period seems to be desirable in guarding against bacterial decomposi-

Mr. G. W. Fuller.

tion of the sewage flowing through the tanks as distinguished from the sludge resting upon the bottom.

The Columbus works seem to have been handicapped considerably by going into service in the late autumn, their biological functions not having become established before the appearance of cold weather. In studying the results as to putrescibility, it should be borne in mind that this test is applied more rigidly than ordinarily is the case elsewhere.

In closing, the writer desires to commend the thorough painstaking investigations of Mr. Clarence B. Hoover, Chemist in Charge, as to the behavior of these disposal works in their various relations to local conditions.

Mr. Gregory.

JOHN H. GREGORY, M. AM. SOC. C. E. (by letter).—The writer is exceedingly gratified that the paper has served to bring out such an interesting and valuable discussion. As various phases of the operation of the works have been covered by others in their discussions, the writer will confine his closing remarks to matters not touched on by them or such as would seem to call for further explanation.

*Water-Works.*—Mr. W. B. Fuller raises the question of the operation of the pumping station by electricity or compressed air. In Mr. Gray's report it was shown that a certain amount of power could be developed from the surplus water flowing over the dam. During certain months of the year, however, the flow in the river is so low that no power would be available, and during others only a small amount. This would require then the installation of a steam boiler plant at the pumping station, and the pumping engines would have to be constructed to operate by steam as well as by electricity or compressed air, or duplicate machinery would have to be put in. The city officials were committed to the construction of only the low dam. The raising of the dam was left to the future. The amount of power available from the low dam was much less than from the high dam. There was no prospect at all that funds for the construction of the power plant at the dam would soon be available, or for many years to come. As stated previously, no funds were available for the construction of the conduit from the dam to the purification works, and, in the writer's opinion, the construction of the conduit and other works is of more importance than the power plant. The city was building a steam-operated municipal electric light plant, which has since been completed, and is in very successful operation. A power plant at the dam could be operated to advantage in connection with the municipal light plant. It was mainly in view of these various factors that it was decided to build only a steam-operated plant at the pumping station.

Several have called attention to the fact that the reservoir is located in the main valley of the river, and that the total flow of the river must pass through the reservoir at all times. The location is not ideal,

but the topography is such that no other solution was possible, except at a prohibitive cost. It was fully appreciated that during floods relatively soft water with high turbidity would have to be treated in the purification works, necessitating the most careful operation to produce a satisfactory effluent. Lateral storage reservoirs, unquestionably, would be of great value, and this point was not overlooked, but, even if a suitable location could be found, they would still be of no service until the conduit was built, and possibly then only by building an additional pumping plant. It is to be hoped that in the future more extended investigations will be made to see if some means cannot be found to furnish the works, during flood stages in the river, with water which will not change so rapidly in character and may be handled more easily. Mr. Gregory.

Attention has been called to the somewhat complex design of the works and to their elasticity. The problem was not a simple one, and the works had to be designed to meet various conditions, as pointed out by Mr. Kimberly. The preliminary experiments were limited, were carried out only on a small scale, and could serve only as a general guide. Had the knowledge which has since been obtained been available when the works were designed, there is no doubt that modifications in certain features of the design would have been made. That the works are not as simple as a plain mechanical filter plant, is granted, and they hardly could be, but when one becomes familiar with the functions of the various parts, the works are not as complex as one would at first thought imagine. As there was lack of knowledge on certain features, it was necessary that the design be more or less elastic. A certain amount of elasticity was absolutely necessary, but too much was undesirable. The engineers tried to provide what in their opinion seemed ample, but, as the writer has pointed out and as Mr. Copeland has confirmed, there was not sufficient elasticity in certain parts. Some modifications have been made, and probably some few others will be carried out at a later date.

Mr. Copeland's discussion is especially valuable in pointing out some of the troubles which may be expected when designing works with limited data. Some of these troubles were of minor importance, such as not providing fine enough screens on the dissolving tanks, an insufficient number of arms on the stirring devices, and making one or two drain pipes too small. These, however, were readily corrected, with little trouble and at slight expense. It was appreciated that, with the chemicals to be handled, sludge deposits were to be expected at certain points, and an unusual number of connections for blowing out with steam and water were provided. Mr. Copeland's discussion goes to show that too much care cannot be exercised in designing the piping for works of this magnitude, especially where some of the chemical solutions must be carried a considerable distance.

Mr. Gregory.

Referring to the coagulant piping, it would seem that lead-lined pipe, even with the most careful inspection, cannot always be relied on. With regard to carrying the coagulant pipe through concrete walls, this is correct, but it should also be stated that at each of these points the pipe is not bedded in the concrete but passes through an iron pipe sleeve, thus permitting the pipe to be removed if desired. In the main dividing wall of the gate-house, the pipe is below the surface of the water, but, to get at it, it is only necessary to lower the water in the settling basins a little more than 1 ft., and in operation the level frequently fluctuates that much. Flange fittings were provided at each grid, and provision was also made for blowing out the piping. As it has been found desirable to be able to add coagulant at two different places at the same time, it would be better to have the pipe above the floor of the gate-house, thus permitting a more direct connection to each measuring device, and it was the writer's understanding that this change was to be made.

Referring to the rate of application of the wash-water to the filters, and the carrying of sand over into the gutters at the maximum rate, the writer would say that this trouble has been experienced in other works, but it can be easily remedied by lowering the level of the sand somewhat, or by raising the edges of the gutters, or by doing both.

The dislodgment of the gravel underdrains in the filters, however, is another matter. In other works with which the writer is familiar no trouble is experienced with the gravel shifting when wash-water is applied at the maximum rate for which the Columbus works were designed. In discussing this matter it is necessary to refer not only to the design but to the operation of the works. The high-water line in the wash-water tank is 20 ft. 2 in. above the tops of the gutters in the filters. In the pipe line from the tank to the filters there is a wash-water controller, with a by-pass. The controller was designed to regulate the rate of application of the wash-water, and is adjustable. The valves admitting wash-water to the filters are operated hydraulically. It is the writer's understanding that the controller is not used, the water passing through the by-pass and its rate of application to the filter being controlled by hand by throttling the gate-valve, the reason being that different filters have to be washed at different rates. If the valve were opened too wide, the full head from the wash-water tank, less friction, would be applied to the gravel underdrains, and dislodgment of the gravel would surely follow. The writer does not say that this has actually occurred, but it would seem to him highly probable. In providing the controller, the writer had in view the double purpose of furnishing a means of measuring the rate of application of the wash-water and of providing means whereby the full head from the tank could not be applied to the filter, as the controller acts as a pressure reducing valve. If it is necessary to wash different filters at different

rates, or to vary the rate during the washing of any one filter, as is sometimes desirable, the writer believes that trouble with dislodgment of the underdrains would be overcome by closing the by-pass and letting the water flow through the controller, setting the latter for the maximum rate necessary, and then throttling the inlet valve by hand for the lower rates. Mr. Gregory.

With regard to Mr. Potter's criticisms of the bacterial removal by the settling basins on certain dates, the writer believes these are sufficiently answered in the discussions by Messrs. W. R. Copeland and C. P. Hoover. On the earlier dates cited, the high number of bacteria in the settled water, especially on February 17th, was evidently due to an insufficient amount of coagulant, and had Mr. Potter in his Table 68 presented all the pertinent data, the reason for the high number in the settled water would have been apparent. It should also be borne in mind that the works were passing through their first winter of operation, and that full knowledge of the amount of and best method of applying the chemicals had not been gained. On the later dates cited, the high numbers were due to growths of non-pathogenic bacteria in the sludge. That the high bacterial counts in the settled water are not due to what Mr. Potter calls the collapse of the settling basins, is evident from an examination of all the data presented. The writer is not aware that any trouble has been experienced in the settling basins by the precipitates sloughing from the side slopes, and in Mr. Copeland's discussion will be found a statement as to the way the sludge accumulates in the basins.

Mr. Potter also brings up the question of the sterilization of the treated water by hypochlorite of lime or soda. That treatment with hypochlorite of lime has been found advantageous at Columbus has been mentioned by both Mr. Copeland and Mr. C. P. Hoover in their discussions, and, as further stated by them, its use has been adopted as an adjunct to the other processes. With regard to Mr. Potter's remarks relative to the "elimination of the filter where water-softening processes are in use, its place being taken by sterilization with hypochlorite of lime or soda," it is possible under certain conditions that such could be the case, but not where the character of the raw water is such that turbidity is a factor, or where the formation of a secondary turbidity takes place in the settling basins. That hypochlorite of lime is an extremely efficient agent in bacterial removal, as demonstrated during the last few years, is hardly open to question, but had the results of this treatment been known at the time the Columbus works were designed, the filters would still unquestionably have been included. Hypochlorite of lime will not remove turbidity. At Columbus, during flood stages of the river, the quantity of chemicals required for water softening is greatly reduced, and not only bacteria, but turbidity, still have to be removed, and for this reason alone the

Mr. Gregory.

filters would be required. Assuming, however, that the filters could be eliminated, the writer believes that Mr. Potter over-estimates the saving when he states that thereby "approximately 40% of the cost of constructing the Columbus plant could have been saved." The items of cost, as given in Table 10, which would be eliminated, would be the filter gallery, the air-wash equipment, the wash-water tank, and the wash-water pipe, a total of $112 720, or 21.2% of the total cost of the purification works, namely, $532 480. The other portions of the works would remain substantially the same, but there would be a slight additional cost for the hypochlorite of lime treatment. The total reduction in cost, therefore, would have been about 20%, instead of 40 per cent.

With regard to the point mentioned by Dr. Rideal as to the principles on which the chemicals are applied, it should be stated that the amount of chemicals required per unit of volume of water, which of course varies greatly with the character of the water, is determined by the chemists in charge from the results of analyses made in the laboratory. The chemical feed regulators manifestly could not perform this function, but with a predetermined ratio of weight of chemical to a unit of volume of water, the regulators automatically maintain this ratio independent of the total volume of water treated. The provision for adding raw water to the settling basins to eliminate traces of caustic alkalinity was included mainly as a corrective measure in case of disarrangement or of an accidental overtreatment of the water with chemicals, and was not for regular use.

Dr. Fowler raises an interesting question as to the operation of water filters on the same principle as sewage sprinkling filters. This subject is still in the experimental stage, and additional data will be looked for with great interest. As applied to Columbus, it might be feasible to rearrange one of the filters so as to operate on this principle, and an experimental investigation of this kind would unquestionably be of value, but to handle the whole supply in this way, while perhaps not impossible, would be impracticable, and would require a large additional expenditure.

As to the point raised by Mr. Hazen relative to the difference in elevation between the water line on filters and in filtered-water reservoirs, there seems to be no uniform practice. At Columbus it is 10 ft., while in some works it is more and in others less. The tendency, generally, with more recent designs, is to provide less head than in the earlier ones. At Columbus there is no reason why a less head could not have been used, as the controllers are enclosed and are capable of operating when submerged, in the manner mentioned by Mr. Hazen. As previously stated, the city is supplied by direct service, it being impossible to build distribution reservoirs at Columbus from which water could be delivered by gravity, and, as the capacity of the filtered-water reservoirs is only 10 000 000 gal., it was thought best to design the

works so as to provide for the filters a maximum available head of 10 ft. with the filtered-water reservoirs full. Mr. Gregory.

Mr. Ellms has presented some valuable data regarding the cost of the water purification works at Cincinnati which engineers will be very glad to receive. The writer agrees with Mr. Ellms that it is often difficult to make a strict comparison of the cost of two works, and this is true in the case of Cincinnati and Columbus. In discussing the figures presented by Mr. Ellms, the writer believes it will be well to supplement Mr. Ellms' discussion with some additional data, so that the reasons for the difference in actual cost per million gallons daily capacity of the two works will be fully understood.

The water of the Ohio River has a much greater average turbidity than that of the Scioto, as may be seen from Table 27, in which the turbidity of the Ohio is given as 225, and the Scioto as 76 parts per million. It would seem, then, only reasonable to assume that a period of sedimentation at least equal to that at Columbus, would be required at Cincinnati, if not greater. The conditions at the two works are as follows: At Columbus the mixing tanks and settling basins have a combined capacity of 16 270 000 gal. for works having a daily capacity of 30 000 000 gal. The period of coagulation and sedimentation is 13 hours. At Cincinnati the coagulation basins have a capacity of 22 660 000 gal. for works having a daily capacity of 112 000 000 gal., giving a period of coagulation and sedimentation of only about 4.9 hours. It is evident, therefore, that there is a very essential difference in the capacities of these parts of the works, and this is very apparent in the comparative cost of the two works.

No mention is made of the two large settling reservoirs at Cincinnati, having a capacity of 330 000 000 gal., and costing $1 418 879, into which the river water is first pumped and settled before being delivered into the coagulation basins. It is possible that Mr. Ellms considered that the Scioto River storage reservoir served the same function at Columbus as the settling reservoirs at Cincinnati, but the writer does not think that such is the case. The storage reservoir at Columbus was built solely for storage purposes, and that it may be considered at times as detrimental rather than of assistance, as far as the purification works are concerned, has been pointed out by others. At Cincinnati, on the contrary, there would seem to be no doubt that the settling reservoirs are of material assistance to the purification works, although, in the light of the present state of the art, it is believed that settling reservoirs having a much smaller capacity would be sufficient. It would seem, therefore, that a more equitable comparison of the cost of the two works, on the basis of millions of gallons daily capacity, would exist if a portion of the cost of the settling reservoirs was charged to the Cincinnati purification works, or, in lieu thereof, the cost of increasing the capacity of the coagulation basins,

Mr. Gregory.

so as to provide the same period of coagulation and sedimentation at Cincinnati as at Columbus, namely, 13 hours.

On the basis of volumetric capacity, no great difference exists in the cost of the coagulation basins at the one works and the combination of the settling basins and mixing tanks at the other, as may be seen from Table 72, the coagulation basins at Cincinnati costing $13 460 per million gallons and the settling basins and mixing tanks at Columbus $13 090 per million gallons. At Cincinnati the coagulation basins are open, are approximately 23 ft. deep, have earth embankments, and are divided into three compartments by a concrete wall and an earth embankment.

TABLE 72.—Comparative Cost of Coagulation Basins at Cincinnati, and Settling Basins and Mixing Tanks at Columbus.

| | Capacity, in millions of gallons. | Cost. | Cost per million gallons. |
|---|---|---|---|
| Cincinnati: | | | |
| Coagulation basins | 22.66 | $304 913 | $13 460 |
| Columbus: | | | |
| Settling basins and mixing tanks | 16.27 | 213 000 | 13 090 |
| Settling basins alone | 15.00 | 168 770 | 11 250 |
| Mixing tanks alone | 1.27 | 44 230 | 34 800 |

That the combined costs, per million gallons of daily capacity, of the head-house, lime-saturator house, storage-house, wash-water tank, offices, and laboratories are greater at Columbus than the corresponding head-house, chemical-house, wash-water tank, offices, and laboratories at Cincinnati, as pointed out by Mr. Ellms, is to be expected, when the relative amounts of chemicals handled are taken into account. In Cincinnati, for the year 1908, the chemicals applied amounted to 2.43 grains per gallon, or a total of 2 783 tons. In Columbus, for the year from December, 1908, to November, 1909, inclusive, the corresponding figures are 14.1 grains per gallon, or 5 237 tons. At Cincinnati a greater volume of water is treated than at Columbus, but at Columbus about six times as much chemical per volume of water treated is used. The figures given for Cincinnati are not sufficiently itemized to make a detailed comparison of the costs, but it would seem as if the offices and laboratories at both works might be left out in a comparison on the basis of the cost per million gallons daily capacity. The offices and laboratories at both works are well equipped, but at Columbus they would as well serve for the handling of 112 000 000 gal. as of 30 000 000 or 40 000 000 gal. daily.

The greater cost of the filters at Cincinnati is due mainly to the difference in the character of the construction. At Cincinnati the

filters are supported on independent foundations, whereas at Columbus they are supported on the roof of the filtered-water reservoir; the valves are operated electrically instead of hydraulically, and the superstructure covers the operating gallery and all the filter tanks, while at Columbus it covers the operating gallery and only a portion of the filter tanks. Mr. Gregory.

The filtered-water reservoir at Cincinnati cost less, on the basis of million gallons daily capacity of works, than did those at Columbus. The difference in cost is due to a difference in conditions. At Columbus the reservoirs are covered and have a capacity of 10 000 000 gal. for works having a daily capacity of 30 000 000 gal., giving a supply of 8 hours. At Cincinnati the reservoir is open, although designed so that a covering may be added, and has a capacity of 19 600 000 gal. for works having a daily capacity of 112 000 000 gal., giving a supply of only 4.2 hours. Here, again, there is an essential difference in the two works, and a more equitable comparison of the cost on the basis of million gallons daily capacity would exist if the Cincinnati reservoir was covered and had the same period of storage capacity as at Columbus, namely, 8 hours. The reservoirs at Columbus cost $9 830 per million gallons capacity, of which about $3 000 is chargeable to the covering. At Cincinnati the reservoir cost $6 190 per million gallons. If the Cincinnati reservoir was covered, and assuming the same cost of covering per million gallons capacity as at Columbus, it would have cost about $9 190 per million gallons, as against $9 830 at Columbus.

From the foregoing will be seen the difficulty of comparing costs on the basis of million gallons daily capacity, unless the conditions are nearly similar. In order, therefore, to make a more equitable comparison of the total cost of the two works on the basis of million gallons daily capacity, it seems to the writer that to the cost of the Cincinnati works should be added the cost of additional capacity in the coagulation basins, 38 000 000 gal., so as to make the period 13 hours, the cost of additional capacity in the filtered-water reservoir, 17 700 000 gal., to make the supply 8 hours, and the cost of covering the larger filtered-water reservoir. With these assumptions, the cost would be as shown in Table 73.

Viewed in this light, it appears that, with the conditions assumed, the Cincinnati works would have cost, per million gallons daily capacity, about the same as the Columbus works. It is probable, however, that, had the Cincinnati works been built in this way, the cost would have been somewhat less than the figures in Table 73, as the larger coagulation basins and filtered-water reservoirs should cost less per million gallons capacity than did those actually built.

*Sewage Works.*—The writer agrees with Mr. Griggs that mechanical means should be provided for cleaning the sand-catcher at the main sewage pumping station. It should be stated, however, that when the

Mr. Gregory.

TABLE 73.—COMPARISON OF COST OF COAGULATION BASINS, ETC., AT CINCINNATI AND COLUMBUS.

| | Total cost. | Cost per million gallons capacity per 24 hours |
|---|---|---|
| Cincinnati (112 000 000 gal. daily): | | |
| Actual construction | $1 278 790 | $11 418 |
| Increase in capacity of coagulation basins, 38 000 000 gal. at $13 460 | 511 480 | ..... |
| Increase in capacity of filtered-water reservoir, 17 700 000 gal. at $6 190 | 109 560 | ..... |
| Covering filtered-water reservoir, 37 300 000 gal. at $3 000 | 111 900 | ..... |
| Total | $2 011 730 | $17 960 |
| Columbus (30 000 000 gal. daily): | | |
| Actual construction | $532 480 | $17 750 |

design was made it was the intention to provide, before the works were completed, a mechanical device for cleaning, and the sand-catcher, although covered, was arranged so that this device could be installed. A large quantity of grit was not expected at the sand-catcher, only such as would require to be cleaned out at infrequent intervals; the cause of the excessive quantity is due mainly to the defective design of the connections between the combined and the intercepting sewers. This defect in the sewerage system was known, and it was part of the general scheme of the sewerage improvements to reconstruct these connections and to provide, at each point, a sand-catcher between the combined sewer and the intercepting sewer where the heavy grit would be deposited.

It was considered essential to intercept as much grit as possible, not only to keep it from being carried to the pumping station and purification works, but so as to avoid in the future the expensive cleaning of the intercepting sewer. The grades on the intercepting sewer are flat, causing low velocities when running full or half full, exceeding 3 ft. per sec. in two stretches only, and falling as low as 1.72 ft. per sec. Under these conditions, aggravated by the discharge of tar into the sewer, it is not surprising that deposits have accumulated which have been expensive to remove. Unfortunately, funds were tied up until the completion of certain contracts, and it was not until the works were nearly completed that funds were in sight to carry out this part of the improvement. Realizing that this work should be done, and also that the writer's connection with the city would shortly come to an end, he made a recommendation that one of his assistants be retained to design these connections and supervise their construction, but no action was taken on his recommendation. Sketches were made for the mechanical cleaning device at the sand-catcher and also

studies for flushing the intercepting sewer, but, unfortunately, these suffered the same fate as the intercepting connections—they had to be left to be carried out at a later date. Mr. Gregory.

The writer is indebted to Mr. Kimberly for calling attention to the omission, in the historical part of the paper, of the report by the Sewerage Commission in 1900. The writer was aware of this report, but, in assembling the large amount of material for presentation in the paper, this document was unfortunately overlooked, and the writer takes this occasion to express his regret for the omission and to say that it was accidental and entirely unintentional.

Mr. C. B. Hoover has referred to the method of disposing of sludge in the river during flood stages, and has pointed out that "It possesses one element of uncertainty, however, as a long-continued low-water stage in the river in the future may make it desirable that land treatment be made available as an alternative." It is possible that some might infer that under such conditions the method of disposal by dilution would have to be given up entirely. The writer does not think that this necessarily follows. If it should happen that the periods of low-water stage in the river are of long duration, requiring thereby the removal of some sludge from the tanks, it would seem as if it would still be possible to take advantage of this exceedingly economical method of disposal, by constructing a tank in which the accumulation of sludge, during the low-water stage, in excess of the maximum quantity which the septic tanks themselves can care for, could be stored until conditions were such that it could be discharged into the river. If a sludge storage tank was not constructed, land disposal would probably have to be resorted to, not necessarily for the total quantity of sludge, but only for the excess quantity just mentioned.

The writer has been especially interested in Mr. C. B. Hoover's discussion of sprinkling nozzles, and notes his preference for a nozzle which has a central spindle giving an annular orifice, rather than one having a single unobstructed orifice. Under certain conditions, the writer would agree with Mr. Hoover, but, as applied to Columbus, he feels that, without more data and experience at these particular works, he cannot, at the present time, agree with him. As stated in the paper, the bars in the finer of the two screens through which the sewage passes at the pumping station are ½ in. apart in the clear. It was solely on this account that the single-orifice nozzle was adopted, in order to reduce to a minimum trouble with the clogging of the nozzles. Mr. Hoover states that 3.5% of the nozzles showed partly or completely obstructed sprays all the time. The writer considers this a highly creditable showing. Had the filters been equipped with annular-orifice nozzles, he believes that there would have been far more trouble with this type of nozzle when discharging sewage which had been only rough-screened, as is the sewage at Columbus. With the annular-orifice nozzle

Mr. Gregory.

all the clogging would have been internal, whereas, with the single-orifice nozzle, the trouble is mainly with material catching on the apex of the cone and on the arms, and this is easily removed. The writer does not think a sufficient number of annular-orifice nozzles have been in use at Columbus to settle definitely the question as to which type is the better for rough-screened sewage. Another item, which should not be lost sight of, is the fact that leaves, blown into the open septic tanks in the fall of the year, are carried over into the distribution systems of the sprinkling filters and cause some of the trouble with the nozzles.

The annular-orifice nozzle was considered for use at Columbus, as mentioned in a previous discussion,* and was not used, for the reason above stated; but, had the sewage been passed through much finer screens, there is no doubt that the annular-orifice nozzle would have been adopted. Much yet remains to be learned on the subject of sprinkling nozzles and the distribution of sewage on sprinkling filters.

With regard to the point raised by Mr. Kuichling as to the meaning of certain of the column headings in Table 16, the writer would say that they have been changed so that he believes there will be no further question as to their meaning. As stated in the paper, "The filters were designed to yield normally 2 000 000 gal. per acre per 24 hours, resting one-half the time, requiring therefore a rate of 4 000 000 gal. per acre per 24 hours when in service." A distinction should be made between "yield" and "rate." The rate is independent of the yield, whereas the yield is dependent on the rate and on the period of time during which the sewage is applied. The rate of filtration is the quantity of sewage which is applied and passes through the filter on a unit of area in a unit of time.

With regard to the disintegration of the cherty material in the broken stone in the sprinkling filters, it should be stated that this has not been and is not expected to be at all serious. Some disintegration was looked for. A harder stone, free from this material, was to be desired, but investigations showed that this could not be obtained within a reasonable distance of Columbus, and the great additional cost of securing such a material was not warranted.

It has been stated that the effluent from the sewage works has not always been uniformly non-putrescible. In the sprinkling filters at the testing station, which gave a non-putrescible effluent with sewage sprayed from a nozzle under a constant head, the sizes of the stone varied from ½ to 2 in. In the sprinkling filters as built in the works, the stone, which was of approximately the same depth as at the testing station, is from 1½ to 3 in. in size in two of the filters, and from 1 to 3 in. in size in the other two. It will be seen that the broken stone in

*Transactions*, Am. Soc. C. E., Vol. LVII, p. 180.

Mr. Gregory.

the works is very much coarser than that in the experimental filters. That the effluent from the large sprinkling filters has not been uniformly as good as from the experimental filters indicates that with the coarser stone either a greater depth of stone is required, with the present distribution, or that a more uniform distribution is needed. It should be stated, however, that, beginning with the operation of the filters under a varying head, controlled by hand in the gate-house, and giving thereby a better distribution, there has been a decided improvement in the character of the final effluent from the works, especially during the last six months.

As mentioned in the paper, it is intended to install in the gate-house means whereby the head on the nozzles will be made to fluctuate automatically, producing thereby a much more uniform distribution of the sewage on the surface of the filters. The installation of the devices for varying the head automatically and giving also a short period of rest has been delayed temporarily because electric power for operating them has not yet been available at the gate-house. As soon as these devices are installed, and this is to be expected in the near future, the writer believes that the sprinkling filters in the works will produce uniformly as good results as did the experimental sprinkling filters.

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TRANSACTIONS

Paper No. 1147

# AGREEMENTS FOR BUILDING CONTRACTS.*

By William B. Bamford, Assoc. M. Am. Soc. C. E.

With Discussion by Messrs. Norman R. McLure, William V. Polleys, Charles H. Higgins, W. G. Wilkins, William A. Boring, J. C. Wait, W. L. Bowman, Charles A. Ruggles, Oscar Lowinson, E. T. Thurston, Jr., John Mason Brown, J. A. L. Waddell, DeWitt V. Moore, Leslie H. Allen, and William B. Bamford.

This paper has been limited to agreements for the construction of buildings, and no attempt has been made to cover the subject of agreements in general, because the writer has given this type special study and also feels that the principles underlying such agreements are readily adaptable to those for other construction, and that, within the limits of this paper, many of the vital questions at issue can be brought out more effectively by taking a concrete case rather than by dealing in generalities.

From the practical standpoint of the building agreement, it matters little whether the person who planned the building and will have charge of it until completion is called an Engineer or an Architect. The only practical difference would be that the word "Engineer" would be used in one case and the word "Architect" in the other, to represent such a person. Therefore, it should be understood that wherever the word "Engineer" is used throughout this paper it is intended to designate a person properly equipped by education, experience, training, or temperament, to lay out, supervise, and direct, in an executive capacity, all work, at any stage, in the erection of a building, from the time it is mentally conceived until it is finished and ready for use.

* Presented at the meeting of February 2d, 1910.

The purpose of this paper is not a defense of the Contractor, as against the Engineer or Architect, but is simply one advocating justice and equity to all parties to a contract. Destructive criticism is easy, but constructive criticism is of a different mould, and should always be welcomed among broad-minded men. In suggesting a new form of Agreement and Schedule of Conditions of Contract, it is hoped that something definite may be accomplished in righting the wrongs that most Engineers will readily admit exist, and nearly everyone has tried by different means to correct. The writer does not imagine that he has discovered some new and patentable truth, but hopes that his studies may have brought into concrete shape some practical suggestions for correcting well-recognized faults. After Engineers and Architects have set about putting their own houses in order, as typified by contract requirements, they can then more fearlessly demand that Contractors right the wrongs for which they alone are to blame.

Much might be said on the general subject of fairness and justice to both Contractor and Owner in the various contract requirements, on the faults of omission and commission by Engineers and Architects, and on their duties, obligations, and responsibilities. These subjects would have a direct bearing on the principles underlying the reasons for many of the contract requirements herein suggested. The legal questions involved in contract requirements are also of great importance. In order, however, to keep this paper within reasonable bounds, its subjects have been abridged, but reference has been made to articles and books where much additional information may be obtained, or where some subjects, only touched upon here, will be found in more amplified form.

## Historical Summary.

In gathering material for a prospective book on Building Specifications and Contracts, numerous recent specifications and contracts were specially obtained from many prominent architects and engineers for the purpose of study and examination. A careful examination of these, as actual working instruments, and a study of recently published works or addresses, have led to the belief that there was probably a need for investigating and discussing the subject of Agreements (or so-called Contracts) in general, and Building Agreements in particular.

The need for a more or less authoritative set of requirements,

applicable to a proper building agreement, has been recognized for many years. To meet such need, the American Institute of Architects, in co-operation with the National Association of Builders, adopted, a number of years ago, the "Uniform Contract." This contract has remained in force, with no very material changes, up to the present time. The last revision was copyrighted in 1905. This contract, with all its defects, is in general use among Architects, as there is no other form, having the endorsement of a representative American organization, to take its place.

In justice to the American Institute of Architects, it should be said that a Standing Committee on the Standardization of Documents was appointed in February, 1906, and has done much excellent work in collecting material for a new building agreement. Early in 1908 the Committee published, for limited circulation, a pamphlet containing a tentative series of forms, to facilitate the making of suggestions or criticisms to assist the Committee in its further study.

It was recently learned from several authoritative sources that the work of the Committee might not be published for some time, possibly years, and, as the writer's work has been entirely independent of the Committee, he has decided to present its results to this Society for discussion.

Several years ago, the writer learned that the Royal Institute of British Architects had spent many years in perfecting a just and equitable building agreement, but investigation revealed the fact that although the Institute had commenced the work more than thirty years ago, it was almost unknown in America.

The more closely the writer analyzed his own work and ideas and compared them with those of the R. I. B. A., the more firmly convinced he became of the excellence of the latter's work. Looking back at the time which has been spent in perfecting this work, and the number of eminent and experienced men who have contributed to it, there should be small wonder at its present superior condition.

While an agreement for which originality could be claimed for the whole, might be of greater personal benefit, it was decided to sink such personal consideration and frankly undertake to revise a most excellent document, to meet American conditions. The Agreement and the Schedule of Conditions of Contract put forward by the writer have been modified, after serious study, from those adopted by the

R. I. B. A., and the language of the original has been retained wherever possible. Such a revised document has a very important practical advantage over an attempt at originality. As many of the requirements vitally modify traditional American practice in many respects, it might be objected to because it has not had the test of sufficient experience to make it advisable for general use. English and American jurisprudence are fundamentally the same, and therefore the laws or judicial decisions of one country are more nearly similar to those of the other than is true of any other two countries. Since the work of the R. I. B. A. was undertaken originally about 1878, and the present documents were approved in substantially their present shape in 1895, and approved in their present shape in 1903 by the Institute of Builders and the National Federation of Building Trades Employers of Great Britain and Ireland, as well as by the Royal Institute of British Architects, they have had, in Great Britain, the test of time and of litigation, and can therefore be accepted with greater confidence as a secure foundation upon which to erect the desirable superstructure.

The following historical sketch of the British document, as given in an address by the President of the Institute, Mr. Aston Webb, on June 13th, 1903, is of much interest:

"The first time the subject was broached was on the 18th January, 1887, when Mr. T. Rickman announced at a Meeting of the Practice Committee that he had been approached by the Secretary of the Institute of Builders with a view to alterations in the existing Heads of Conditions of Contract. The Committee agreed to consider the question, and a Sub-Committee was formed. The Sub-Committee submitted their draft of General Conditions to the Practice Committee on the 18th December 1888, and for the following year the draft was considered by the Practice Committee. Negotiations were then instituted (December 1889) with the Institute of Builders. On the 29th May 1891 the Committee considered the draft as altered by the Institute of Builders, and negotiations with that Body were continued through the year. On the 9th August 1892 the first Conference between the Practice Committee and the Institute of Builders was held, the representatives of the Practice Committee being Messrs. Henry Currey, H. C. Boyes, G. E. Grayson, Edwin T. Hall, and T. M. Rickman. Negotiations then continued for two or three years, but unfortunately it was found impossible to come to an agreement. In 1895 the negotiations were dropped, and in July of that year the Institute Form of Contract, which was in use from that date to April, 1901, was issued.

"On the 5th December 1898 the Secretary of the Institute reported that he had had an interview with the Secretary of the Institute of Builders with reference to an agreement between the two Bodies on the Arbitration Clause, and a Sub-Committee of the Council, consisting of Messrs. Aston Webb, E. A. Gruning, John Slater, Wm. Emerson, Thomas Blashill and Edwin T. Hall, was appointed to confer with the Builders. Several meetings of the joint representatives were held, and on the 8th October 1900 the Institute of Builders forwarded the Report of the Joint Committee to the Council and stated that they were prepared to adopt it. On the 10th December the Council submitted the revised Paper to the General Body. The Arbitration Clause, however, as revised, met with such strong opposition that the Council referred the matter again to the Institute of Builders urging the modifications required to make the Clause acceptable to the R. I. B. A. After some further correspondence it was announced in April 1901 at a General Meeting that the negotiations between the Council and the Institute of Builders for a uniform Contract had failed, and at a Special General Meeting held on the 15th April 1901 the present Form as revised by the R. I. B. A. was sanctioned. On the 19th January 1903 the President reported to the Council that the President of the Institute of Builders had expressed the willingness of the Builders to accept the Institute Form as it now stood, with the addition of a proviso to Clause 16. The matter was referred to a Committee of the Council, who on the 18th May 1903 reported that they had conferred with Mr. King and Mr. Greenwood on behalf of the Builders, who had agreed to accept the Institute Form subject only to the modifications now proposed. The President of the Institute of Builders was then requested to send a formal communication to the Council stating that his Institute and the National Federation of Master Builders were prepared to accept the two Forms of Agreement and Conditions issued by the R. I. B. A. provided the alterations were agreed to; and that the Council would then recommend the General Body to agree to the alterations."

The present set of forms is thus adopted by both the Royal Institute of British Architects and the Institute of Builders. The debates on the various provisions of the Agreement* are well worth serious study.

### Bibliographical Notes.

The following references are to a few articles or books relating to various matters affecting building agreements, and are given for the benefit of those desiring to make a more extended study of the subject:

* *Journal*, Royal Institute of British Architects, Vols. 2, 8 and 10.

"General Notes on Specifications and Contracts," by William B. Bamford, Assoc. M. Am. Soc. C. E. *The American Architect,* serial beginning Sept. 15th and ending Oct. 6th, 1909.

"The Engineer's Fault," by John C. Wait, M. Am. Soc. C. E. (A discussion of specifications, contracts, and lawsuits.) *Proceedings,* The Municipal Engineers of the City of New York, 1905. Reprint in *Engineering News,* June 9th, 1905.

"The Legal Position of Architects in Relation to Certificates and Awards," by J. A. Strahan. (A paper read before the Royal Institute of British Architects, Jan. 28th, 1895.) Abstract in *The Builder,* Vol. LXVIII, p. 82.

"In Contract Work, either Public or Private, is it Preferable to make Separate Contracts for the Different Branches of Trades Involved, or to Combine all under one General Contract?" An Informal Discussion. *Transactions,* Am. Soc. C. E., Vol. XLIX, p. 1.

"The Position of the Consulting Engineer, and his Duties in Relation to Inspection and the Enforcement of Contracts." By Albert J. Himes, M. Am. Soc. C. E. *Transactions,* Am. Soc. C. E., Vol. LVI, p. 104.

"Uniformity of Requirement and Clearness of Specification in Agreements for the Graduation of Railroads." By W. F. Dennis, M. Am. Soc. C. E. *Transactions,* Am. Soc. C. E., Vol. LVIII, p. 321.

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Revisions, *Journal,* Vol. 2, 1894-95.

Amendments, *Journal,* Vol. 8, 1900-01.

History of Agreement, *Journal,* Vol. 10, 1902-03, p. 416.

"Engineers' Contracts and Specifications from a Contractor's Point of View," by James W. Rollins, Jr., M. Am. Soc. C. E. *Journal, Association of Engineering Societies,* July, 1907.

"Different Plans of Letting Contracts," by Frank B. Gilbreth. (Paper read before the American Public Works Association.) Reprint in *Engineering News,* Oct. 18th, 1906.

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"The Engineer in Construction Contracts," by John C. Wait, M. Am. Soc. C. E. *Transactions,* Association of Civil Engineers of Cornell University, 1902.

"Engineers' Specifications." (Observations on specifications in general and the legal effect of clauses of particular hardship to contractors.) *The Engineer* (London), Dec. 30th, 1904.

"The Influence of Specifications on Commercial Products," by C. B. Dudley, M. Am. Soc. C. E. (Presidential address before the

American Society for Testing Materials.) *Proceedings,* American Society for Testing Materials, 1904. Reprint in *The Engineering Record,* July 9th, 1904.

"Arbitrations: A Text-Book for Arbitrators, Umpires, and All Connected with Arbitrations, more especially Architects, Engineers, and Surveyors, in Tabulated Form, with the Chief Cases Governing the Same, and an Appendix of Forms, Statutes, Rules, etc.," by Professor Bannister Fletcher, F. R. I. B. A., London (1904). Crown 8vo, 149 pages, cloth, 3d ed., revised and largely rewritten.

"Architects' Law Reports (illustrated): A Series of Revised Reports of Cases Decided in the Superior Courts, of Importance to Architects, Surveyors, and Others Interested in the Construction and Maintenance of Buildings and Streets in London and the Provinces," compiled by Arthur Crow, F. R. I. B. A., Legal Editor; A. F. Jenkins, Barrister-at-law. London, Vol. I, Dec., 1904, 125 pages, 4to, paper cover; Vol. II, Dec., 1905, 275 pages, 4to, paper cover; Vol. III, Dec., 1908, 4to, paper cover.

"Building Cases: Being a Digest of Reported Decisions Affecting Architects, Surveyors, Builders, and Building Owners," by F. St. John Morrow, LL.D., Barrister-at-law. London (1906), Large 8vo.

"Building Contracts, Building Leases, and Building Statutes (English), with Precedents of Building Leases and Contracts, and Other Forms Connected with Building, and the Statute Law Relating to Building, with Notes and Cases under the Various Sections, Together with an Appendix of Unreported Building Cases," by Judge Emden. London (1907), 800 pages, 4th ed., revised, Large 8vo.

"Conditions of Contract," by Frank W. Macey. London, 1904.

"Engineering and Architectural Jurisprudence: A Presentation of the Law of Construction for Engineers, Architects, Contractors, Builders, Public Officials, and Attorneys-at-Law," by John C. Wait, M. Am. Soc. C. E. New York (1898), lxxx + 905 pages, 8vo, cloth.

"Law of Contracts," by John M. Brown (the author). Wash. (1907), 80 pages, 8vo, cloth.

"Statutory Provisions Relating to Government Contracts," by John M. Brown (the author). Wash. (1908), 49 pages, 8vo, cloth.

### Divisions of Contracts.

Building contracts may be said to be divisible into four parts or divisions.

*1.—Matters Preliminary to Contracts.*—Being the terms under which a contract is awarded, and giving the general information necessary before the execution of the agreement. It would include the "Form of Agreement" and "Schedule of Conditions of Contract" as given hereafter.

*2.—Agreement (or so-called Contract).*—Being the instrument executed between the Owner and Contractor, legally and formally binding them to fulfill their obligations. It should properly include the "Schedule of Conditions of Contract."

*3.—Specifications.*—Being the detailed written description of the method of construction and of the quality and kind of materials to be furnished.

*4.—Drawings.*—Being the detailed, graphic design of the work to be done, with the quantity and sizes of materials.

This paper treats only of the Agreement (or so-called Contract).

The Agreement, preferably, should not contain any matters concerning the details of construction, these belonging properly to the specifications. There are, however, a number of legal requirements which could be included in the Agreement or in the Specification. Legally, they would be just as binding in one as in the other. These matters will be mentioned under the heading "General Conditions."

## Reasons for Contracts.

A building contract is entered into by the Owner in order to obtain the services of a contractor who is skilled in that particular kind of work, and by the Contractor because he expects to make a certain profit in remuneration for his services and knowledge. Assured of his profit, it is immaterial to the Contractor what kind of work the Owner or Engineer may desire to have done, but if the Contractor's profit is not assured, he becomes vitally interested in anything that may tend to affect this prospective profit. With the Contractor, the work is purely a business proposition; he expects to make a certain profit for doing a particular amount of work. He must make a legitimate profit; his business life depends on it; and the more he feels this slipping away from him the more diligently will he find ways and means to reimburse himself. Even the best of contractors will try hard to obtain this profit in one way or another, else they must ultimately be forced from business and leave the field to those who are probably less competent contractors but shrewder business men.

A contract is intended to insure that an Owner will obtain a definite piece of work for a stated sum and within a given time, and to insure that, for doing this, a Contractor will be paid stated sums of money at definite times. The contract, therefore, should be drawn so that the

Owner can demand and obtain his work and the Contractor his payments with the least delay and difficulty.

It is thought that the provisions of the Agreement and Schedule of Conditions of Contract given hereafter will protect more equitably the interests of all parties, and permit the Engineer to enforce more certainly the proper fulfillment of the contract obligations than has been possible under the majority of such documents which have come to the writer's notice.

### Systems of Contracting.

At present the systems of contracting used in building work may be divided into two general classes, the lump-sum system and the various percentage systems. They are often designated by the manner in which the work is to be paid for, as:

1.—Lump sum;

2.—Cost, plus a percentage;

3.—Cost, plus a percentage—where the General Contractor takes estimates for sub-branches of work, and makes lump-sum contracts, with the Engineer's approval;

4.—Cost, plus a percentage, with guaranteed limit;

5.—Cost, plus a fixed sum;

6.—Cost, plus a fixed sum, with a bonus if cost is less than a fixed sum, and a penalty if it exceeds such sum.

Of these, the lump-sum system is the most usual, and is theoretically the best. Such a system pre-supposes that the contract defines the work to be performed, and that a contractor, therefore, can determine accurately what the execution of such work will cost. If, however, the contract requirements are indefinite, the Contractor is never certain, no matter how conscientious he may be, that he may not be required, under broad or ambiguous clauses of the contract, to furnish more than he honestly understood would be required from his reading of the contract when estimating. Thus he may be forced to do work at a net loss instead of a profit. Under the various percentage systems, on the contrary, the Contractor is assured of his profit, no matter how much work he may be required to do.

The lump-sum contract is superior to the percentage type because it more truly fosters fair and open competition, and is more economical, as has been demonstrated amply by many men of ripe experience.

This presumes that the drawings and specifications describe completely and accurately everything that the Contractor must do or furnish, especially where an expense is involved. If this is not done, the Contractor's prices become mere gambles on probabilities, and not accurate estimates of actual costs plus a legitimate profit. In such a case is it to be wondered at that a Contractor will fight at every legitimate opening in order to protect his final profit? He is not always able legally to demand additional compensation for the work which has actually cost him more than the estimated amount, therefore his only opportunity to make up his losses and come out with a fair total profit is by obtaining good prices for additional work, or, if it does not appear that there will be any such worth while, the Contractor must find flaws in the contract and endeavor to get all the extra money he can, through technicalities or otherwise.

With the irresponsible or dishonest Contractor there need be no sympathy, but by far the greater number of Contractors only desire their legitimate profit, and the prospect of making a fair profit by hard, honest work is none too bright at the present time, under the usual lump-sum contract.

Contractors have found that the easiest and most practical way to overcome the disadvantages of the lump-sum estimates is by the various percentage systems. The Contractor is thus assured of his profits, and the Owner and Engineer can change or increase the work to their hearts' content, as all additional expense involved is borne by the Owner.

Assuming that the Contractor is honest, and that the bills and statements he presents for payment are correct, and have all discounts, except a cash discount deducted, the cost of percentage work is apt to exceed the cost of work done under a lump-sum contract. The reasons for most of this increase are not hard to find. The Contractor, not being responsible for the cost, and having his profits assured, readily makes any changes and does work as directed, no matter how expensive or uneconomical such work may be, and the Owner does not realize how expensive his fads or fancies will be until the work is completed. Then again, if the percentage is based on the total cost, there is not the incentive for the Contractor to become as zealous in obtaining the closest prices for materials as he would under a lump-sum contract.

Another most serious objection to percentage work is due to the

fact that mechanics are inclined to loaf, even under the most careful supervision, and it is hard to get as much work out of them as under the lump-sum system. They seem to feel that as their employer, the Contractor, will not suffer any loss, there will be no harm done, or they will not be in danger of losing their positions.

Many of the most serious objections to the percentage system have been overcome in varying degrees under Systems 3, 4, 5, and 6. These systems have much to commend them, and, with all their faults, they will eventually supersede the lump-sum system, unless more care is taken to make contracts complete and accurate.

The English method of "Quantity Surveying" is another excellent attempt to overcome the worst objections to the lump-sum system of estimating, but, as at present in use, it would be too cumbersome for American practice. There the Owner or Engineer has the work to be done itemized in detail, and on this itemized statement, submitted to all Contractors, they fill in their prices. These lists go into matters in minute detail, and, as all Contractors estimate on the same list, the advantage is obvious. The Royal Institute of British Architects had approved forms, which are only slight modifications of the one for lump-sum contracting, in which the principal change is in making the "Quantities" a part of the contract. Under such a contract, the Contractor would be able to obtain compensation for all items not mentioned specifically in the "Schedule of Quantities."

### Practical and Equitable Contracts.

Many contracts appear to be drawn by the Engineer solely on the assumption that the Owner's interests must be most carefully guarded against failure by the Contractor to fulfill his agreements properly. In the past, when profits were sufficiently liberal, Contractors could afford to take chances that "club-clauses" would not be strictly enforced, and profits lost by unfair clauses could be made up on "extras." To-day, however, competition is sharper, and profits are too often figured on too slender a margin to permit a Contractor to "take care" of losses caused by unfair clauses. No wonder, then, that the Contractor becomes more and more technical and troublesome over small omissions or errors, whereas, before, he could charge these minor matters to profit and loss, or good-will. The chances which a Contractor takes that an Owner will not be fair-minded should not be overlooked. An

Owner may become very exacting, and may insist on "strict and literal" compliance with the letter of the specifications and contract, and may place an Engineer in a very embarrassing position by referring to and insisting on the literal fulfillment of certain ambiguous conditions or the "taking of every pound of flesh," against the Engineer's better judgment.

The value of a just contract to the Owner and the Engineer is as great as its value to the Contractor. A just contract, provided it is accurate and free from ambiguity, cheapens the cost of work by eliminating the necessity for sums to cover possible contingencies; it broadens real competition, and encourages lower estimates; it ensures more rapid erection, and also acts as a powerful regulator of the mutual understanding and confidence in the fairness of all parties. Fairness, like oil for machinery, is necessary to prevent friction.

The Agreement is only one of the divisions of a contract. It is the specifications and drawings, together, which must give the Contractor a clear and complete knowledge of the work he must perform and the materials he must furnish, and should contain all the information necessary to permit him to make an accurate estimate and to carry out the work properly. The specification requirements should define clearly the result, the accomplishment of which is the object of the contract. It is a general statement of the work to be performed, a description of the materials, the quality required, and the workmanship to be performed, with definite limits as to what tests must be made in order to determine compliance with the requirements of the contract, or what defects would be sufficient cause for rejection.

Specification writing cannot be acquired successfully without practice and without broad knowledge, practical experience, and a careful study of the various materials and methods of construction and their relative costs. As ideas and methods change and improve, as a result of experience, so specifications should be changed to keep abreast of the times. An inexperienced writer is very apt to be uneven in his descriptions, writing at unnecessary length upon matters with which he is familiar, and covering his ignorance of equally important matters by the brief and ambiguous direction that "the work shall be done to the entire satisfaction of the Engineer," "whose decision is to be final and binding on all parties." These statements are too often an admission that the Engineer did not know what he desired, or that the Owner

had failed to express a preference and, therefore, had been left with unlimited future choice.

As previously stated, the ultimate object of a contract is to insure to the Owner that he will obtain a definite finished product, of a certain kind, for a particular cost, and in a given time; and to insure to the Contractor that he will obtain certain sums of money at definite times for doing a definite amount of work; and the Engineer is looked upon as the arbitrator or judge, to see that both parties receive their full justice under the contract. Contracts, therefore, should be drawn so that the Owner can demand and obtain his work and the Contractor his payments with the least delay and difficulty.

Engineers have always claimed to be arbitrators between Owner and Contractor, and not the representative solely of one party. This position is a proper one, but to-day it is more of a myth than a fact. The anomalous position is brought about, not because Engineers are desirous of being unfair, but because of the agreements (or contracts) generally used, which make it extremely hard, if not almost impossible, for Engineers to be fair if they try to conform to the agreement provisions.

It might be claimed that one of the most practical benefits to Engineers and Architects, in the more general use of an agreement similar to the one herein suggested, might be that it would not so insidiously "lead us into temptation" but would "deliver us" from many of the pitfalls lurking unsuspectingly around many present contracts.

While there is abundant room and great need for material improvement in specifications, it must be recognized that, with the limitations to the best of human endeavors, it will be extremely difficult, even for the most conscientious and painstaking, to prepare specifications for large work which may not contain some unfair requirements, when viewed from the Contractor's standpoint. We can come near to the goal, certainly much nearer than is at present the practice, but possibly our slight oversight may mean a Contractor's heavy loss.

The writer, therefore, strongly feels that one of the most practical steps toward the realization of contracts which will be fair and just to all parties will be made by the more general acceptance of the principles contained in the following forms of Agreement and Schedule of Conditions of Contract, and the adoption of similar provisions in contracts.

It is suggested that the following Agreement and Schedule of Conditions of Contract, be read through first as a whole, in order to obtain a general knowledge of their scope, omitting the reading of the notes following. They should then be read, article by article, with the comments after each.

AGREEMENT.

(For Lump-Sum Contracts.)

*This Agreement,* made the ..... day of ....., in the year One Thousand Nine Hundred and ....., by and between ....., of ....., hereinafter called the Contractor, and ....., of ....., hereinafter called the Owner.

*Witnesseth,* that the Contractor and Owner, for the considerations hereinafter named, agree as follows:

*Article I.*—The Contractor agrees to provide all materials and perform all works for the.....
(here briefly describe works)
.....
.....
of a..... at .....
(here briefly describe type of building) (here briefly describe location)
shown on drawings numbered ..... and as described in the Specifications marked.....; prepared by ....., hereinafter called the Engineer; and to do all things required of him by the Drawings and Specifications and subject to the Conditions set forth in the Schedule hereto annexed (hereinafter referred to as "the said Conditions").

*Article II.*—The Contractor agrees to complete the works by and at the time or times hereinafter stated, to wit:.....
.....
.....

Liquidated damages should be a matter for special consideration in each separate contract. Many Engineers and Owners seem to desire them, possibly for the moral effect on Contractors. The history of the legality of such provisions should cause them to be used with caution.

In many cases the following clause might be as far as it would be advisable to go toward obtaining just and reasonable damages for delay in completion:

"The Contractor agrees that the time for completion of the works shall be considered as of the essence of the contract, and he agrees that

for liquidated damages he will pay the Owner for the cost of all extra inspection, and for all amounts paid for rents, or for more protracted services on the part of the Engineer, or Clerk of the Works, or both, and other expenses entailed by the Owner by delay in completing the contract, and the Owner shall be entitled to retain from the amount otherwise to become due to the Contractor an amount sufficient to reimburse properly the Owner for such expenses. Provided, however, that the sum collected as aforesaid for liquidated damages shall not exceed the sum of $..... for each and every day's delay not caused by the Owner, or otherwise as provided in the said Conditions, Section XXIV (subject to Arbitration)."

*Article III.*—The Owner agrees to pay the Contractor for the execution of the contract ..... dollars ($.....) in current funds subject to additions and deductions as provided in the said Conditions, and upon the presentation of the certificates of the Engineer, as follows:

Before the ..... day of each month, the Contractor may submit to the Engineer a written statement showing (*a*) the value of the work and materials actually wrought into the building to the first of the month, (*b*) the value of materials delivered at the building but not incorporated into the work, and shall deduct the aggregate of previous payments. On or before the ..... day of the same month, the Engineer shall issue a certificate for .....% of the value of work as executed in the building, until the balance retained by the Owner amounts to the sum of $....., after which time the payments shall be for the full value of the work subsequently executed. The Contractor shall be entitled, under the certificate to be issued by the Engineer, to receive payment of ....., being a part of the said sum retained in hand when the works are practically completed, and in like manner to payment of the balance within a further period of ..... months, or as soon after the expiration of such period of ..... months as the work shall have been finally completed, and all defects made good according to the true intent and meaning hereof, whichever shall last happen. The Engineer, however, shall have authority to retain out of any monies actually due the Contractor only such sums as are provided by the said Conditions, Section XXX.

The manner of payment could be varied in many ways, as the conditions of the particular case made it necessary. The principle underlying the form suggested above, however, is important.

As before stated, it is as essential that the Contractor shall be able to demand and obtain his payments as that the Owner shall be able to obtain the work for which he pays.

In Article III the Contractor's right to definite payments is expressed clearly. The Engineer must issue a certificate for money due, and the Owner must pay the amount due. It should be noted that the Engineer is allowed ample discretionary power to withhold any money not justly due, as provided by Section XXX of the Conditions. Thus the obligations become fairly clean cut. If the Contractor's work is not done properly, there is ample power to withhold money to cover definite defects. On the other hand, if the Engineer or Owner withhold any payments without just cause, the Contractor has recourse to Arbitration, under Section XXXIV of the Conditions, or to terminate the contract, under certain contingencies, as provided in Section XXXIII.

The idea of retaining percentages until the completion of the work is intended to insure its proper completion. The usual American practice of retaining an unchanging percentage from start to finish is unnecessarily extravagant, and in contracts involving large amounts is more harmful than beneficial. After the work has been approximately half completed, the remainder should be paid for in full without retaining a percentage. Of course, additional sums can be retained to cover known defects. The sum retained when the work is half completed is usually sufficiently liberal to cover possible contingencies, and is just as effectual as to continue to increase it until completion.

*Article IV.*—It is mutually agreed that the term "the Engineer" in the said Conditions shall mean the said .....or in the event of his death or ceasing to be the Engineer, for the purpose of the contract, such other person as shall be nominated for that purpose by the Owner, not being a person to whom the Contractor shall object for reasons considered to be sufficient by the Arbitrators or Arbitrator mentioned in the said Conditions. Provided, always, that no person subsequently appointed to be Engineer under this contract shall be entitled to disregard or overrule any decision, or approval, or direction, given or expressed by the Engineer for the time being.

The purpose of Article IV is to cover cases which may be unusual but are generally very troublesome when they occur. It would prevent a subsequent Engineer from altering at will matters of personal opinion or choice of his predecessor. No two minds are exactly alike, and few Engineers or Architects have exactly similar tastes. Should an Engineer desire to change work which may be purely matters of opinion

or judgment of both himself and his predecessor, such changes should not be paid for by the Contractor, but by the Owner, if he decides to follow the suggestions of his adviser. Of course, defective work should be condemned at any time, when discovered. Should an Engineer desire to change some orders of his predecessor, and take the ground that certain work should be done as a part of the contract, he should not have arbitrary power to enforce his will, but could order the work done as provided by Section XVII of the Conditions, leaving to the Contractor the right of appeal to arbitration, under Section XXXIV, if he desires.

*Article V.*—It is mutually agreed that the said Conditions shall be read and construed as forming a part of this Agreement, and the parties hereto will respectively abide by and submit themselves to the conditions and stipulations, and perform the agreements on their parts, respectively, in such Conditions contained.

*Article VI.*—The Contractor and Owner, for themselves, their successors, executors, administrators, and assigns, hereby agree to the full performance of the covenants and agreements herein contained.

*In Witness Whereof,* the Contractor and Owner have hereunto set their hands and seals, the day and year first above written.

In presence of

..... ..... [SEAL]
..... ..... [SEAL]

SCHEDULE OF CONDITIONS OF CONTRACT.

*I.—Drawings and Specifications.*—The works shall be erected in accordance with the directions and to the reasonable satisfaction of the Engineer, in accordance with the Contract Drawings and Specifications, and in accordance with such further drawings, details, instructions, directions, and explanations as may from time to time be given by the Engineer. If the work shown on any such further drawings or details, or explanations be, in the opinion of the Contractor, extra to that comprised in the Contract, he shall, before proceeding with such work, give notice in writing to this effect to the Engineer. In the event of the Engineer and Contractor failing to agree as to whether or not there is any extra, and of the Engineer deciding that the Contractor is to carry out the said work, the Contractor shall accordingly do so, and the question whether or not there is any extra, and if so the amount thereof, shall, failing agreement, be settled by Arbitration, as provided in Section XXXIV, and the Contractor will be paid accordingly.

This section covers the troublesome question of work shown by details, etc., being in excess of the contract requirements. It might be reasonable to assume that the Engineer would know better than anyone else whether his details require extra work, and the Contractor should be permitted at any time to recover the value of such work upon proving that it was extra to the contract. There are many sound objections to such a course, and the more satisfactory of the two evils would seem to be to require the Contractor to notify the Engineer of any extra work, before proceeding with it, as a precedent to obtaining extra compensation.

*II.—Contractor to Provide Everything Necessary.*—The Contractor shall provide everything necessary for the proper execution of the works, within the limits established by the Drawings and Specifications, according to the true intent and meaning of the Drawings and Specifications taken together, whether the same may or may not be particularly shown on the Drawings or described in the Specifications, provided that the same is reasonably to be inferred therefrom; and if the Contractor finds any discrepancy in the Drawings, or between the Drawings and Specifications, he shall immediately refer the same to the Engineer, who shall decide which shall be followed. Figured dimensions shall be followed in preference to the scale, and figures on large-scale drawings shall take precedence over those at smaller scale.

*III.—Copies of Drawings and Specifications.*—The Contract Drawings and Specifications shall remain in the custody of the Engineer, and shall be produced by him at his office as and when required by the Contractor or the Owner. Three complete copies of all Drawings and of the Specifications shall be furnished by the Engineer, free of cost, to the Contractor, for his own use. The Engineer shall furnish to the Contractor within ..... days after the receipt by him of a request for the same, any details which, in the opinion of the Engineer, are necessary for the execution of any part of the work, such request to be made only within a reasonable time before it is necessary to execute such work in order to fulfill the contract. A complete set of such copies and details shall be kept on the works until the completion thereof, and the Engineer or his representative shall at all reasonable times have access to the same, and, as instruments of service, all drawings are the property of the Engineer and shall be returned to the Engineer by the Contractor at the time of making the final payment under the contract.

*IV.—Conform to Laws, Regulations, Etc.*—The Contractor shall conform to the provisions of all the State building and sanitary laws, and with all municipal or local ordinances, rules, and regulations

relating to building and to the preservation of the public health and safety, also with all regulations of the Board of Fire Underwriters and Fire Insurance Authorities having jurisdiction, and of any Water and Lighting Companies with whose systems the structure is proposed to be connected, and, before making any variations from the Drawings and Specifications that may be necessary by so conforming, shall give to the Engineer written notice, specifying the variation proposed to be made, and the reason for making it, and apply for instructions thereon. In case the Contractor shall not in due course receive such instructions, he shall proceed with the work, conforming to the provisions, ordinances, rules, and regulations in question, and the variation thus necessitated shall be dealt with under Section XXXIV. All contract requirements over, above, and beyond the said provisions, ordinances, rules, and regulations, shall be fully complied with. The Contractor, at his own expense, unless the law specifically requires the Owner to do so, shall obtain all necessary permits and licenses, give all necessary notices, and pay all legal fees.

The laws, ordinances, etc., of States and municipalities are often very divergent in their requirements, and in places positively contradictory. The meaning of many of their requirements, together with a great many of those of various Fire Insurance Authorities, is not easy to determine by the most careful reading. Then again, the local authorities may have discretionary powers, and their "personal preferences" may be difficult to obtain, even by local men. Thus it would appear that, if an Engineer cannot interpret correctly the local requirements in his drawings and specifications, it is unfair to place the responsibility, by a blanket clause, on the Contractor. If, therefore, the authorities require work to be done in a different manner than that called for by the contract documents, and such work involves additional expense, the Owner, and not the Contractor, should pay for the same.

*V.—Setting Out Work.*—The Contractor shall set out the work in accordance with the Owner's survey and the Engineer's drawings, and, during the progress of the building, shall correct at his own expense any errors arising from inaccurate setting out, unless the Engineer shall decide to the contrary.

It is advisable that the Owner have a survey made, and guaranteed, if desired, by some recognized Title Guaranty Company. With this survey and the drawings, the Contractor should be held to lay out the work correctly; but, to renounce all responsibility for the survey or

drawings, and endeavor to place the responsibility for all conditions, both known and unknown, on a Contractor, is not good business policy, nor keen professional foresight, though there may be specific cases apparently to justify such a course.

*VI.—Foreman.*—The Contractor shall keep constantly on the works a competent general foreman, and any directions or explanations given by the Engineer to such foreman shall be held to have been given to the Contractor.

*VII.—Assignment of Contract.*—The Contractor shall not, without the written consent of the Engineer, assign this agreement, and, before subletting any portion of the works, shall notify the Engineer of such fact, in writing. No sub-contractors, to whom the Engineer has made written objections, shall be employed, and the Contractor shall assume full responsibility for all his sub-contractors.

Sub-contractors are not legally recognized as parties to a contract, but, in many cases the power is assumed of dictating to a Contractor what persons he must employ as sub-contractors. Such a course is not only unfair, but might cause legal difficulties later, should the Contractor take the ground that he is not responsible for the acts of a sub-contractor, not of his own selection, but who was forced upon him by the Engineer or Owner. In the foregoing section the Engineer may disapprove of sub-contractors who are not satisfactory, but he is not permitted to dictate who must be employed as sub-contractors. Where the Engineer approves a sub-contractor, it can be implied that he considers that the person whom he may approve will be satisfactory, while, by confining himself to the disapproval of unsatisfactory sub-contractors, no such satisfaction can be implied, as the persons finally employed may be entirely unknown to the Engineer.

*VIII.—Work by Other Contractors.*—The Contractor shall permit the execution of work by any other mechanics or trades employed by the Owner, and shall afford them every reasonable facility for the proper erection of their work. The Owner agrees not to employ any other mechanics or trades on the work against whom the Contractor shall make what the Engineer considers a reasonable objection, or who will not enter into a contract with the Contractor guaranteeing the due performance of his work and indemnifying the Contractor against valid claims which may arise during the performance of the work.

The object of this section is simply to minimize the chances for disagreements between independent contractors and their making

claims to the Owner for damages done to them by other contractors. By this section, if a General Contractor is responsible for the completion of certain work, he is permitted to make reasonable objection to other independent Contractors before they are employed, and to exact a warranty for valid claims arising out of the work. If they agree to indemnify each other, the Owner has then fulfilled his obligations; then any disagreements must be settled between the individual Contractors, and the Owner can demand with a clear conscience that they shall perform their contract obligations, and settle their own differences.

*IX.—Materials, Etc., to Conform to Specifications.*—All materials and workmanship shall be of the respective kinds described in the Specifications, and the Contractor, upon the request of the Engineer, shall furnish him with vouchers to prove that the materials are such as are specified. The Contractor shall also furnish duplicate labelled samples of materials and workmanship, for the Engineer's approval, and the materials and workmanship furnished shall be equal to the approved samples.

*X.—Dismissal of Workmen.*—The Contractor, on the written request of the Engineer, shall immediately dismiss from the works any person employed thereon by him, who, in the opinion of the Engineer, may be incompetent, or who misconducts himself, and such person shall not be again employed on the works without the permission of the Engineer.

*XI.—Access to Work.*—The Engineer and any person authorized by him shall at all reasonable times have access to the works, and the Engineer and his representatives shall at like times have access to the workshops of the Contractor or other places where work is being prepared for the building.

*XII.—Clerk of Works.*—The Clerk of the Works or other representative shall be considered to act solely as inspector, and under the Engineer, and the Contractor shall afford him every facility for examining the works and materials. The Clerk of the Works or other representative shall have no power to revoke, alter, enlarge, or relax any requirements of the contract, except in so far as such authority may be specifically conferred by a written order of the Engineer.

*XIII.—Work to Be Opened Up.*—The Contractor, at the request of the Engineer, and within such times as the Engineer shall name, shall open for inspection any work covered up; and should the Contractor refuse or neglect to comply with such request, the Engineer may employ other workmen to open up the same. If the said work has been covered up in contravention of the Engineer's instructions, or if, on being opened up, it is found to be not in accordance with the Drawings and Specifications or the instructions of the Engineer, the expense of open-

ing and covering it up again, whether done by the Contractor or such other workmen, shall be borne by, and shall be recoverable from, the Contractor, or may be deducted, as hereafter provided. If the work has not been covered up in contravention of such instructions, and be found in accordance with the said Drawings and Specifications or instructions, then the expense aforesaid shall be borne by the Owner and be added to the contract sum: provided always that in the case of foundations, or other urgent work thus opened up and requiring immediate attention, the Engineer, within a reasonable time after the receipt of notice from the Contractor that the work has been so opened, shall make or cause the inspection thereof to be made, and at the expiration of such time, if such inspection shall not have been made, the Contractor may cover up the same, and shall not be required to open it up again for inspection except at the expense of the Owner.

This section seems to indicate the fairest practical way of solving a perplexing problem.

*XIV.—Removal of Work.*—During the progress of the works, the Engineer shall have power to order in writing from time to time the removal from the works, within such reasonable time or times as may be specified in the order, of any materials which in the opinion of the Engineer are not in accordance with the Specifications or the instructions of the Engineer, the substitution of proper materials, and the removal and proper re-execution of any work executed with materials or workmanship not in accordance with the Drawings and Specifications or instructions; and the Contractor shall forthwith carry out such order at his own cost. In case of default of the Contractor to carry out such order, the Owner shall have power to employ and pay other persons to carry out the same; and all expenses consequent thereon or incidental thereto shall be borne by the Contractor, and shall be recoverable from him by the Owner, or may be deducted by the Owner from any monies due or that may become due to the Contractor. If, in the opinion of the Engineer, it is not expedient to remove materials delivered or alter work done which is not in accordance with the contract, the Owner may deduct the difference in value of the materials as delivered and the work as done and that required by the Drawings and Specifications, together with a fair amount for damages, which sum shall be determined by the Engineer (subject to Arbitration).

*XV.—Defective Work.*—Any defects, shrinkage, or other faults which may appear within.....months from the completion of the works, and, in the opinion of the Engineer, arising from materials or workmanship not in accordance with the Drawings and Specifications or the instructions of the Engineer, or any damage to pointing by frost, appearing within the like period, shall, upon the direction in writing of the Engineer, and within such reasonable time as shall be

specified therein, be amended and made good by the Contractor at his own expense, unless the Engineer shall decide that he ought to be paid for the same; and, in case of default, the Owner may employ and pay other persons to amend and make good such defects, shrinkage, or other faults or damage, and all expenses consequent thereon or incidental thereto shall be borne by the Contractor and shall be recoverable from him by the Owner from any monies due or that may become due to the Contractor. Should any defective work have been done or should any defective materials be supplied by any sub-contractor employed on the work who has been nominated or approved by the Engineer, as provided in Sections VII and XXIX, the Contractor shall be liable to make good in the same manner as if such work or materials had been done or supplied by the Contractor and had been subject to the provisions of this and the preceding Section.

*XVI.—Copy of Quantities, Etc.*—The Contractor, if required before executing this agreement or before making application for any payment, shall furnish to the Engineer, upon a blank form prepared by him, a correct, verified, itemized statement, showing the quantities of labor and materials that will be required to perform the principal items of the contract, together with their prices; and the amount included in his estimate for each general item of work to be furnished complete and in position, including in each item its due proportion of expense and profit, the sum of the different items equalling the total amount of the proposal. The above schedule shall be for the use of the Engineer, at his discretion, only in preparing estimates for payments on account to the Contractor.

If this section is read in connection with Sections XVII and XVIII, it will be seen that possibly many apparently desirable modifications are covered by the provisions of those two sections.

*XVII.—Variations and Extras.*—The Contractor, when authorized by the Engineer, or as provided by Section IV, shall vary by altering, adding to, or deducting from the contract requirements; such authorization is to be sufficiently proven by any writing or drawing signed by the Engineer, or by any subsequent written approval by him, but the Contractor shall make no variation without such authorization. No claim for extra compensation will be allowed unless it shall have been executed under the provision of Section IV, or by the authority of the Engineer, as herein mentioned. Such an extra is hereinafter referred to as an authorized extra.

Variations in the contract (or extras) is one of the most troublesome phases of lump-sum contract work. By the provisions of this section and Section XVIII, with the final redress to arbitration under

Section XXXIV, it is hoped, that the greater part of such controversies can be adjusted satisfactorily.

*XVIII.—Price for Extras.*—No variation shall vitiate the contract; but all alterations, additions to, or deductions from the contract requirements, which may have been made with the authority of the Engineer, or without his authority, provided he gives subsequently a written sanction to such omission, shall be valued in one of the four following ways, as may be selected by the Owner:

*A.*—By Estimate and Acceptance of a Lump Sum. The Contractor shall submit an estimate for making the variation contemplated, and in case an agreement as to price cannot be reached, the Engineer may order the work to proceed and the Contractor shall forthwith proceed with such variation and leave the price to be settled by Arbitration. A tentative amount, however, will be allowed by the Owner, equal to the proportion of the amount of the estimate conceded by both the Owner and Contractor, and payments will be made on the basis of such amount "without prejudice" until the correct amount shall be determined by Arbitration.

*B.*—By Unit Prices. Where the Contractor shall have given, in his estimate for the contract, or in subsequent accepted estimates, unit prices for specified parts of the work, the Engineer may make an award of a sum based on these unit prices, subject to Arbitration.

*C.*—By Net Cost. In this case the Contractor will be paid the actual net amount paid by him for materials; after all trade discounts, except a *bona fide* cash discount, have been deducted; plus the cost of labor or material required to erect and finish the work properly; plus ....% for profit, general office superintendence, and other general office expenses not peculiar to this contract; plus ....% per month on the actual cost for reproducing the plant as used for such extra work, for plant rental. The total net cost shall not exceed the usual reasonable cost for similar work, unless the Contractor can prove conclusively that the excess was due to exceptional and unavoidable difficulties or conditions. At required intervals, of not less than seven days, the Contractor shall render detailed statements and vouchers, and the Engineer will award an amount as the net cost, subject to Arbitration. In variations involving the omission of work, the amount to be deducted for such omission shall be based on the net cost as given above, plus ....% for prospective profit.

*D.*—By Cost Plus a Lump Sum. In such cases the Contractor shall submit an estimate which he agrees the variation shall not exceed, plus a sum for profit. The Contractor, at required intervals, of not less than seven days, shall render detailed statements and vouchers of the net cost, on the same basis as given under *"C"* above, except that no profit shall be included. If the actual cost is less than that

given in his estimate, the Contractor shall receive, in addition to the lump sum profit,....% of the difference between the actual cost and the amount of his estimate. If the actual cost is greater than that given in his estimate, the Contractor shall receive, in addition to the amount of his estimate, only ....% of the difference between the actual cost and the amount of his estimate.

The foregoing methods of determining the price to be paid for variations to the contract (or extras) with the redress to Arbitration (Section XXXIV), is in principle the most equitable method that has come to the writer's notice, for solving one of the most vital parts of a contract—the proper compensation for legitimate extra work. This section, in detail, is entirely different from anything which the writer has seen in use, and he suggests for it special consideration. In principle, it is similar to the requirements of the Royal Institute of British Architects.

*XIX.—Damage to Persons and Property.*—The Contractor shall indemnify and save harmless the Owner of and from any and all claims and demands which may be made by reason of (1) any injury or damage suffered or sustained by any person or corporation, caused by, or alleged to have been caused by, any act or omission of the Contractor or his agents, servants, workmen, employees, or sub-contractors, in the course of the performance of the work; and (2) any injury or damage suffered or sustained by any such agents, servants, workmen, employees, or sub-contractors, however caused, in or about said building; and the Contractor, at his own cost, expense, and risk, shall defend any and all actions, suits, or other legal proceeding that may be brought or instituted against the Owner on any such claim or demand, and pay and satisfy any judgment that may be rendered against the Owner in any such action, suit, or other legal proceeding, or result thereof; provided, however, that this section shall not be construed as an assumption by the Contractor of any liability to the Owner for any injury or damage caused by an employee of the Owner who is not a Contractor or sub-contractor, or an agent, servant, workman, or employee of a Contractor or sub-contractor engaged in the performance of work in or about said building.

*XX.—Damage to Work.*—The Contractor shall assume the responsibility for, and repair at his own expense, all damage to his work, or the work of other Contractors, or to the building and contents, caused by the installation of work or by the carelessness or negligence of himself, his sub-contractors, or employees. He shall also be responsible for, and make good, any damage to adjoining property, caused by any movement or settlement, or by material or implements falling upon the

same during construction, or for any other cause for which the Owner may be held liable, and shall thoroughly complete the whole of the works.

*XXI.—Patent Infringement, Etc.*—The Contractor shall indemnify and save harmless the Owner from any and all claims and demands which may be made by reason of any infringement, or alleged infringement, of any patent, patent rights, or claim, caused, or alleged to have been caused, by the use of any apparatus or appliances, or portions thereof, furnished or installed by the Contractor; and the Contractor, at his own cost, expense, and risk, shall defend any and all actions, suits, or other legal proceedings that may be brought or instituted against the owner on any such claim or demand, and pay and satisfy any judgment or decree that may be rendered or adjudged against the Owner in any action, suit, or other legal proceeding or result thereof.

*XXII.—Insurance.*—During the progress of the works, the Owner will maintain insurance on said works, in his own name and in the name of the Contractor, against loss or damage by fire or lightning, and the policies will cover all work incorporated in the building, except that of excavation and foundations below the level of the ground, and all materials for same in or about the premises, and be made payable to the Owner, for adjustment between the parties hereto, as their interests may appear. At the end of each month the Contractor shall deliver to the Owner a statement showing the total value of work done and materials delivered, as herein described, to that date, and the owner will maintain said insurance in accordance with the latest statement thus delivered.

The objection to most insurance clauses is the difficulty of adjusting properly the interests as they may appear. Fire Insurance Companies usually hold such payments until both parties sign an agreement stating the proportionate amounts each party is to receive. This adjusting, in case of a disagreement, may consume considerable time, and delay the continuance of the work. Under Section XXII the amount of the insurance is payable directly to the Owner, and as he receives monthly a statement from the Contractor and insures the Contractor in accordance with such statement, it is fairly simple to estimate the Contractor's loss at any time. If the Owner neglects to insure himself properly, he then has no one but himself to blame.

*XXIII.—Damages for Delay.*—Should the Owner claim damages for delay in the completion of the works, the Engineer, if, in his opinion, any damages be payable, will make an award on the basis stated in the Agreement, and will write the amount across the face of the final certificate as "the amount to be deducted from the face

hereof for delay in completion of the work" (subject to Arbitration). Thereupon the Engineer's services in this matter shall terminate, except as provided under Section XXXIV.

Should the Contractor, by his own fault or negligence, unnecessarily delay the completion of the work, thereby necessitating unusual or more protracted services on the part of the Engineer or the Clerk of the Works, or both, the Owner shall be entitled to retain from the amount otherwise to become due the Contractor an amount sufficient to reimburse properly either the Engineer or the Clerk of the Works, or both, for such protracted or unusual services (subject to Arbitration).

This section should be read in connection with any damages to be allowed under Article II of the Agreement. It should be distinctly stated in the Agreement whether or not the specified sum for damages includes the protracted services of the Engineer, etc., herein mentioned. In many cases compensation for such protracted services might be all the damage that should justly be demanded.

*XXIV.—Extension of Time.*—If, in the opinion of the Engineer, the work be delayed by *force majeure* or by reason of any exceptionally inclement weather, or by reason of instructions from the Engineer in consequence of proceedings taken or threatened by, or disputes with, adjoining or neighboring owners, or by the work or delay of other Contractors or mechanics engaged or nominated by the Owner or the Engineer, and not referred to in the Specifications, or by reason of authorized extras or additions, or in consequence of any notice reasonably given by the Contractor in pursuance of Section IV, or by the combined action of workmen, in no wise caused by or resulting from default or collusion on the part of the Contractor, or in consequence of the Contractor not having received in due time necessary instructions from the Engineer for which he shall have specifically applied in writing, the Engineer will make a fair and reasonable extension of time for completion in respect thereof. In case of such combined action of workmen, the Contractor shall, as soon as may be, give to the Engineer written notice thereof; but the Contractor shall, nevertheless, use his best endeavors to prevent delay, and shall do all that may reasonably be required, to the satisfaction of the Engineer, to proceed with the works.

The usual practice is to grant an extension of time to a Contractor equal to the time which he may be delayed, provided he gives notice of such delay within 48 hours. The reasons for which extensions may be granted are usually very few, and not always of the most importance. The section suggested above will probably be objected to as

not definitely specifying the length of the extension of time that may be allowed. The Engineer is empowered to make a fair and reasonable extension of time for completion, and he can thus take into account matters which it would be hard to cover by an arbitrary clause. Should either party feel aggrieved by the length of time of the extension, it has the right of appeal to Arbitration (Section XXXIV).

*XXV.—Suspension of Work by Contractor.*—If the Contractor, except on account of any legal restraint upon the Owner preventing the continuance of the works, or on account of any of the causes mentioned in Section XXIV, or in case of any certificate being withheld or not paid when due, shall suspend the works, or, in the opinion of the Engineer, shall neglect or fail to proceed with due diligence in the performance of his part of the contract, or if he shall more than once make default in the respects mentioned in Section XIV, the Owner, by the Engineer, shall have power to give notice in writing to the Contractor requiring that the works be proceeded with in a reasonable manner and with reasonable despatch. Such notice shall not be unreasonably or vexatiously given, and must signify that it purports to be a notice under the provisions of this section, and must specify the act or default on the part of the Contractor upon which it is based. After such notice shall have been given, the Contractor shall not be at liberty to remove from the site or works, or from any ground contiguous thereto, any plant or materials belonging to him which shall have been placed thereon for the purpose of the works; and the Owner shall have a lien upon all such plant and materials, to subsist from the date of such notice being given until the notice shall have been complied with. Provided always that such lien shall not, under any circumstances, subsist after the expiration of thirty-one days from the date of such notice being given, unless the Owner shall have entered upon and taken possession of the works and site, as hereinafter provided. If the Contractor shall fail for .... days after the time given in such notice to proceed with the works as therein prescribed, the Owner shall be at liberty to provide any such labor or materials, and to deduct the cost thereof from any money then due or thereafter to become due to the Contractor under the contract.

The general purport of this section is similar to the majority of similar American clauses. Its wording, however, is freer from uncertainties, and deserves careful attention.

*XXVI.—Termination of Contract by Owner.*—If the Contractor shall fail for .... days after such notice has been given as provided in Section XXV, to proceed with the work as therein prescribed, and if the Engineer shall then certify that such refusal, neglect, or failure

is sufficient ground for such action, the Owner may enter upon and take possession of the works and site, and of all plant and materials thereon (or on any ground contiguous thereto), intended to be used for the works, and all such materials as above mentioned shall thereupon become the property of the Owner absolutely, and the Owner shall retain and hold a lien upon all such plant until the works shall have been completed under the powers hereinafter conferred on him. If the Owner shall exercise the above power he may engage any other person to complete the works, and exclude the Contractor, his agents, and servants, from entry upon or access to the same, except that the Contractor or any one person nominated by him may have access at all reasonable times to inspect, survey, and measure the works. And the Owner shall take such steps as, in the opinion of the Engineer, may be reasonably necessary for completing the works without undue delay or expense, using for that purpose the plant and materials above mentioned, in so far as they are suitable and adapted to such use. Upon the completion of the works, the Engineer shall certify the amount of the expense properly incurred consequent on and incidental to the default of the Contractor as aforesaid, and in completing the works by other persons. Should the amount thus certified as the expenses properly incurred be less than the amount which would have been due to the Contractor upon the completion of the work by him, the difference will be paid to the Contractor by the Owner; should the amount of the former exceed the latter, the difference shall be paid by the Contractor to the Owner. The Owner will not be liable to make any further payment or compensation to the Contractor for or on account of the proper use of the plant for the completion of the works under the provisions hereinbefore contained other than such payments as are included in the contract price. After the works shall have been thus completed by persons other than the Contractor, under the provisions hereinbefore contained, the Owner shall give notice to the Contractor of such completion, and may require him from time to time, before and after completion, to remove his plant and all such materials as aforesaid as may not have been used in the completion of the works, from the site. If such plant and materials are not removed within a reasonable time after notice shall have been given, the Owner may remove and sell the same, holding the proceeds, less the cost of their removal and sale, to the credit of the Contractor. Any notice to be given to the Contractor under this clause shall be given by leaving the same at the place of business of the Contractor, or by a registered letter sent to him at that address.

This section conforms in substance to the generally accepted American practice, but its wording is more definite, and it leaves fewer loopholes for argument or controversy.

*XXVII.—Net Cost.*—The words, "Net Cost," or the initials, "N. C.," used in the Specifications, for materials to be obtained and installed by the Contractor, shall mean, unless otherwise stated in the Specifications, the sum paid to merchants, after deducting all trade discounts, for such materials, in the ordinary course of delivery, but not deducting discount for cash, and such sum shall be exclusive of special cartage, the cost of installation, and Contractor's profit.

*XXVIII.—Provisional Sums.*—The provisional sums mentioned in the Specifications for materials to be supplied or for work to be performed by special contractors or mechanics, or for other works or fittings to the building, shall be paid and expended at such times, and in such amounts, and to and in favor of such persons, as the Engineer shall direct, and sums thus expended shall be payable by the Contractor without deduction or discount, or (without prejudice to any rights of the Contractor existing under the contract referred to in Section XXIX) by the Owner to the said Contractors or mechanics. The value of works which are executed by the Contractor in respect of provisional sums, or in additional works, shall be ascertained as provided by Section XVIII. At the settlement of accounts the amount paid by the Contractor to the said contractors and mechanics, and the said value of such works executed by the Contractor, shall be set against all provisional sums or any sum provided for additional works, and the balance, after allowing *pro rata* for the Contractor's profits at the rate of ....%, unless different rates are contained in the Contractor's original estimate, shall be added to or deducted from the contract sum, provided that in estimating the amounts paid as last herein provided no deductions shall be made by or on behalf of the Owner in respect of any damages paid by the sub-contractor to the Contractor, the intention being that the Contractor and not the Owner shall have the benefit of any such damages.

There are many cases where important matters may not be definitely determined before the execution of a contract. The practice in many cases is to insert a blanket clause giving almost unlimited selection to either Owner or Engineer. In such case a Contractor must make a shrewd guess at the amount to include in his estimate. Or something as nearly as possible to what may be required may be specified, and afterward the problem is to reconcile the cost of the work as specified with the work as required. The idea of having Provisional Sums inserted in a contract to cover matters not distinctly determined, is not new, but the above section may suggest a wording which will overcome many of the previous objections to such Provisional Sum clauses.

*XXIX.—Sub-Contractors.*—All contractors, merchants, mechanics, or others executing any work, or supplying any materials for which net cost prices or provisional sums are included in the Specifications, who may at any time be nominated, selected, or approved by the Engineer are hereby declared to be sub-contractors employed by the Contractor; but no sub-contractor shall be employed upon the works against whom the Contractor shall make what the Engineer considers reasonable objections, or who shall not enter into a contract with the Contractor upon terms and conditions consistent with those in this Contract, and securing the due performance and maintenance of the works supplied or executed by such sub-contractors, and indemnifying the Contractor against any claims arising out of the misuse by the sub-contractor or his workmen of any scaffold erected or plant used by the Contractor, or that may be made against the Contractor in consequence of any act, omission, or default of the sub-contractor, his servants or agents, and against any liability, as given under Sections XIX, XXI, or XXII.

This section is intended to cover cases where it becomes desirable to have special Contractors execute work covered by Provisional Sums. In many cases particular types or makes of articles cannot be obtained excepting from special parties. To require a Contractor to employ such parties and not be relieved from responsibility for their actions, is a difficult problem. This section will prevent a Contractor, who may be under heavy penalty to complete his work, from being compelled to employ a particular Contractor for a sub-branch, who may absolutely refuse to indemnify the Contractor if he fails to complete his work on contract time, or to give a warrant for the faithful performance of the work.

*XXX.—Payment and Certificate.*—The Engineer shall issue his certificates for payments due the Contractor in accordance with the terms of the Agreement, provided, however, that the Engineer may withhold only such proportion of any sum due as in his judgment will cover the expense of the liens as given under Section XXXI, or of correcting such violation as given in Section XIV, and such payments shall not become due until violations are properly corrected (subject to Arbitration) or the liens are removed as hereinafter provided. No certificate given or payment made under the contract, nor partial or entire occupancy of the building by the Owner, shall be construed as an acceptance of defective work, or of improper materials, or as condoning any omission, provided, however, that in the case of a partial or entire occupancy of the building by the Owner, the Contractor shall have been given notice of all defects or omissions reasonably noticeable

before such occupation. No certificate, final or otherwise, shall be construed as relieving the Contractor from his obligations to make good any defects discovered in his work after the completion and acceptance of the same, nor as a waiver of any specific obligation the Contractor may have assumed as to the durability of his works. The acceptance by the Contractor of the payment of the final certificate shall constitute a waiver of all claims against the Owner under or arising out of the contract. The Contractor, before each payment falls due, shall submit to the Engineer a requisition therefor and shall, if required, submit therewith an itemized statement of the quantities and value of works in general items performed to date, and such statements shall be made in form provided or approved by the Engineer.

The provisions of this section are of great importance in any contract. Its importance is in its wording, and not because it contains any new principle.

*XXXI.—Liens.*—If at any time there shall be evidence of any lien or claim, for which, if established, the Owner or the premises might be made liable, and which would be chargeable to the Contractor, the Owner shall have the right to retain out of any payment then due, or thereafter to become due, an amount sufficient to indemnify himself against such lien or claim until the same shall be effectually discharged, or bonded; and should there prove to be any such claim after all payments are made, the Contractor shall refund to the Owner all monies that the latter may be compelled to pay in discharging any lien upon said premises made obligatory in consequence of the Contractor's default. Before the final payment shall become due, the Contractor shall deliver to the Owner a satisfactory release of all liens against the premises on the part of all persons who have delivered materials for use in, or performed work on, said premises, including a release from the Contractor himself.

*XXXII.—Unfixed Materials.*—When the Contractor shall have received payment of any certificate in which the Engineer shall have stated that he has taken into account the value of any unfixed materials intended for the works, and placed by the Contractor thereon, or upon ground adjacent thereto, all such materials shall become the property of the Owner, and shall not be taken away, except for the purpose of being used on the building, without the written authority of the Engineer; and the Contractor shall be liable for any loss of or damage to such materials.

*XXXIII.—Termination of Contract by Contractor.*—Should the Owner not pay the Contractor any sum certified by the Engineer within the times respectively named in the Agreement, the Contractor shall give to the Owner written notice of the non-payment, and should the Owner not pay any such sum within the period of .... days from

the date of delivery of such notice at the Owner's address, or sent to him there in the ordinary course of mail by registered letter, or if the Owner shall become bankrupt or file any petition for liquidation of his affairs, and if his Receiver in Bankruptcy shall repudiate this contract, or if the Receiver shall be unable to show, within .... days, to the reasonable satisfaction of the Contractor, his ability to carry out the contract, and to make all payments due or to become due thereunder, or if the works be stopped for .... months, under an order of the Engineer or any Court of Law, the Contractor shall be at liberty to terminate the contract by notice in writing to the Engineer, and to recover from the Owner payment for all work executed and for any loss he may sustain upon any plant or material supplied or purchased for the purpose of the contract. In ascertaining the amount of such payment, the rates contained in the Contractor's original estimate shall be followed, or, where the same may not apply, rates proportionate to the prices therein contained, as far as the same are applicable.

Few American contracts contain any provision permitting a Contractor to terminate a contract on any condition whatsoever. In fact, most contracts are filled with clauses designed to bind a Contractor hand and foot so that, no matter what may happen, he is certain to remain a party to the contract. The absolute unfairness of many such requirements is hard to account for, except that they have been inherited from times when work and conditions were totally different from those existing to-day. The fairness of Engineers including within contracts a section similar to the above should be apparent from a careful reading of the section.

*XXXIV.—Arbitration.*—Provided always that in case any dispute or difference shall arise between the Owner, or the Engineer on his behalf, and the Contractor, either during the progress of the works or after the termination, abandonment, or breach of the contract, as to the construction of the contract or as to any matter or thing arising thereunder (except as to matters left to the sole discretion of the Engineer under Sections II, VII, X, XIV, and the exercise by him, under Section XIII, of the right to have any work opened up), or as to the withholding by the Engineer of any certificate to which the Contractor may claim to be entitled, then either party shall forthwith give to the other notice of such dispute or difference, and such dispute or difference shall be and is hereby referred to the arbitration and final decision of three disinterested arbitrators, one chosen by the Owner, one by the Contractor, and the third chosen by these two arbitrators. The decision of any two of these arbitrators shall be final and binding on both parties hereto. If the parties hereto mutually agree,

one arbitrator may be appointed in place of the three named as above, and his decision shall be final and binding on both parties.

When the time for submitting matters to arbitration, as herein provided, has arrived, either the Owner or the Contractor may appoint an arbitrator and demand the appointment of an arbitrator by the other party. Should the party filing notice of appeal to arbitration as herein provided fail to choose an arbitrator or to agree on a single arbitrator within seven days after receiving a written request from the other party, his right to arbitration in such matters shall lapse; should the other party fail to choose an arbitrator or to agree on a single arbitrator within seven days after receiving a written request so to do, then such dispute or difference shall be and is hereby referred to the arbitration and final decision of ....., or in the event of his death, or unwillingness or inability to act, of ....., or in the event of his death, or unwillingness or inability to act, of a person to be appointed on the request of either party after giving notice to the other party, by the President, for the time being, of the American Institute of Architects or of the American Society of Civil Engineers, and the award of such arbitrator shall be final and binding on both parties.

Such reference, except on the question of certificate, shall not be opened up until after the completion or alleged completion of the works, unless with the written consent of the Owner or Engineer and the Contractor. The arbitrator, or arbitrators, shall have power to open up, review, and revise any certificate, opinion, decision, requisition, or notice, save in regard to the said matters expressly excepted above, and to determine all matters in dispute which shall be submitted to him or them, and of which notice shall have been given as aforesaid, in the same manner as if no such certificate, opinion, decision, requisition, or notice had been given. Should either party refuse, or neglect, to supply the arbitrator or arbitrators with any papers or information considered necessary by him or them to arrive at a decision in the matters referred to him or them, which papers or information have been specifically demanded in writing, he or they are hereby authorized and empowered by both parties to the contract to proceed in *ex parte* proceedings, and such proceedings shall be final and binding.

Upon every or any such reference, the costs of and incidental to the reference and award, respectively, shall be in the discretion of the arbitrator or arbitrators, who may determine the amount thereof, or direct the same to be taxed as between attorney and client, or as between party and party, and shall direct by whom and to whom and in what manner the same shall be borne and paid.

This section caused more debate among the members of the Royal Institute of British Architects and more differences of opinion be-

tween the British Architects and Builders than all the other sections combined. The discussion on this subject, in the *Journal* of the Royal Institute of British Architects, is especially worthy of study.

The importance of this section justifies the most careful study which can be given to it. Around it would center the much discussed authority of the Engineer or Architect to settle all matters of every kind and description. Everyone who has exercised such powers must realize that while they are theoretically desirable, their proper curtailment would unravel a very difficult situation, and would permit questions being considered in a more equitable light for all parties.

The usual American arbitration clause is a delusion and a snare to all parties. Many have felt that it was a guaranty of redress for possible wrongs, only to be awakened when its provisions were called into action.

It should be noted, of course, that the English "Arbitration Act, 1889," is a very practical document, and probably gives more legal security to the enforcement of arbitration clauses than would be possible under the laws of most of the States. Arbitration clauses are used in many contracts, and they should be made as practical and workable as possible; then, if it is found that even under the most practical of clauses the State laws need strengthening to make the term "arbitration" a reality and not a myth, there would be a good foundation on which to advocate an arbitration act similar to the English statute.

The above section leaves the Engineer as the deciding party between both Owner and Contractor, but should either party formally dissent from his decision, a notice can be given of an appeal to arbitration. Such appeals, however, will not be actually submitted to the arbitrators until the substantial completion of the work. This seemed to be the point of greatest disagreement between the British Architects and Builders. The former indorsed the above procedure, while the Builders desired the matters to be submitted to arbitrators at any time. The objection to permitting submissions at any time is that, under the broad powers which it is desirable to grant to arbitrators, it would cause confusion during construction, and make it possible to confuse hopelessly the power of the Engineer and the arbitrator. After the substantial completion of the work, such conflict cannot well arise. The Engineer being supreme during construction and after completion, the

arbitrator has power to review only certain of the Engineer's decisions to which written exception has been taken, as herein provided. Of course, in the matters which are referred to arbitration, the decision of such arbitration is final. Such a policy, by its very broadness, would tend to make Owners, Engineers, and Contractors more willing to listen and consider the grievances, real or imaginary, of the other parties.

Section XXXV is intended to dissuade both parties from taking unnecessary or trivial appeals from an Engineer's decision.

While the foundation of the arbitration section is laid on the lines of that of the Royal Institute of British Architects, it differs in many details, and its importance justifies giving the R. I. B. A. section in full, for purposes of comparison.

ARBITRATION SECTION OF ROYAL INSTITUTE OF BRITISH ARCHITECTS.

"32.—Provided always that in case any dispute or difference shall arise between the Employer or the Architect on his behalf and the Contractor, either during the progress of the works or after the determination, abandonment, or breach of the Contract, as to the construction of the Contract or as to any matter or thing arising thereunder (except as to the matters left to the sole discretion of the Architect under Clauses 4, 9, 16, and 19, and the exercise by him under Clause 18 of the right to have any work opened up), or as to the withholding by the Architect of any certificate to which the Contractor may claim to be entitled, then either party shall forthwith give to the other notice of such dispute or difference, and such dispute or difference shall be and is hereby referred to the arbitration and final decision of ....., or, in the event of his death or unwillingness or inability to act, of ....., or, in the event of his death or unwillingness or inability to act, of a person to be appointed on the request of either party by the President for the time being of the Royal Institute of British Architects, and the award of such Arbitrator shall be final and binding on the parties. Such reference, except on the question of certificate, shall not be opened until after the completion or alleged completion of the works, unless with the written consent of the Employer or Architect and the Contractor. The Arbitrator shall have power to open up, review, and revise any certificate, opinion, decision, requisition, or notice, save in regard to the said matters expressly excepted above, and to determine all matters in dispute which shall be submitted to him, and of which notice shall have been given as aforesaid, in the same manner as if no such certificate, opinion, decision, requisition, or notice had

been given. Upon every or any such reference the costs of and incidental to the reference and award, respectively, shall be in the discretion of the Arbitrator, who may determine the amount thereof, or direct the same to be taxed as between solicitor and client or as between party and party, and shall direct by whom and to whom and in what manner the same shall be borne and paid. This submission shall be deemed to be a submission to arbitration within the meaning of the Arbitration Act, 1889."

*XXXV.—Damages for Submission to Arbitration.*—In submitting to arbitration questions in dispute, or differences involving a variation in the amount of the contract, both the Owner and the Contractor shall have the option of submitting their appeals in separate items or groups of items. In which case the arbitrators or arbitrator, in awarding a judgment on each item or group of items, are authorized and directed by both parties to the contract, to award to the party whose contention is sustained, in addition to the sum actually determined as correct, an amount equal to .....% of such amount. Such additional sum shall be added to or deducted from the amounts in question as the case may require. Should a claim be set aside in whole, or should the nature of the case otherwise require it, the amount of such additional award shall be added to or deducted from the amount due the Contractor on the contract. These additional sums shall be considered as damages for the time and trouble incident to such appeal.

The object of this section is to act as a check to prevent appeals to arbitration becoming the fashion rather than the exception. While the principle of this section is considered good, the ability to enforce it is not settled in the writer's mind.

### General Conditions.

The endeavor has been to make the Agreement and Schedule of Conditions of Contract as broad and general as is consistent with good practice. There are additional conditions which may be desirable or essential for particular buildings, but as these conditions are special and of only limited, if not personal, application, it is unwise to attempt to write such in a general set of Conditions of Contract.

Legally, such conditions would be just as binding upon a Contractor whether they were given as a part of the Agreement or were placed in the Specifications. The writer, therefore, advocates placing in the fore part of a Specification a chapter headed "General Conditions," under which would be placed special requirements of a more

or less legal and general nature, which, for the purpose of the particular building, might have been made a part of the Schedule of Conditions of Contract.

The following are given as samples of clauses which might be found under a heading "General Conditions." It must be distinctly understood that these clauses are given only as samples, without comment. The writer does not endorse them for general use, and, except in isolated cases, he considers that many of the provisions might be more harmful than beneficial.

*Checking Documents.*—The Contractor shall carefully study and compare all drawings, specifications, and other information given to him by the Engineer, both as to figures, materials, and methods of construction, and shall report in writing to the Engineer for rectification any error, inconsistency, or omission therein, which he shall discover, or any modification he considers necessary or desirable for the stability or economical construction of the building.

*Doing Work in Freezing Weather.*—Work shall not be done when the temperature where work is being done is below 28 degrees Fahr., or if exposed to rains, except by special permission of the Engineer. Frozen materials shall not be built upon.

*Engineer's Approval.*—All materials or work specified to be of an "approved" type, construction, or finish, shall be submitted to and approved by the Engineer before being used or executed. Where materials, quality, or finish are not distinctly specified, samples shall be submitted to and approved by the Engineer before using same. An approval by the Engineer shall be understood to mean that it is conditional upon the work being in conformity with the contract requirements. No approval of deviation from contract requirements shall be implied, but shall be specifically mentioned in the Engineer's written approval. (See Section IV, Schedule of Conditions of Contract.)

*Materials and Workmanship.*—All materials shall be new, and all materials and workmanship shall be the best of the respective kinds contemplated by the contract, unless otherwise specified.

*Contemplated Work.*—The work to be executed under the contract consists in general of a ....., constructed and completely finished in every particular ready for furnishing, within the limits shown on the Drawings and described in the Specifications, except (*a*) elevators, (*b*) lighting fixtures, (*c*) electrical, (*d*) heating work, (*e*) or work specifically excepted or made subject for separate bids.

*Contract Documents.*—(See Agreement, Article I.)

*Definitions.*—The following definitions of works, terms, etc., shall be understood to govern their use throughout the Contract:

*Approved.*—The word "approved," as applied to any material, manner or mode of construction, shall be construed as though followed by the words "by the Engineer."

*Best.*—The term "best," or "best quality," shall be taken to mean that there is no better quality or finish of material of the grade specified or reasonably implied, obtainable on the market supplying the vicinity, or that there is no better class of work mentioned, reasonably obtainable.

*Net Cost.*—(See Conditions of Contract, Section XXVII.)

*Provide, Etc.*—For the sake of brevity, and to avoid needless repetition, the imperative mood has been largely used throughout the specification. Wherever it is used it shall be understood to mean, "The Contractor shall furnish all material and perform all labor necessary to .....," and these words shall be read into the sentence.

*Provisional Amount.*—(See Conditions of Contract, Section XXVIII.)

*Drawings.*—The Contractor shall furnish to the Engineer at proper times all shop and setting drawings or diagrams which the Engineer shall deem necessary to carry out the work. Each drawing or diagram shall give all the information required by the nature of work which it is intended to govern. These drawings or diagrams shall conform strictly to the Engineer's drawings and specifications, and where possible upon measurements taken from existing work. No deviation from the Engineer's drawings and specifications shall be made unless by special written order. The Engineer will inspect such drawings, but his purpose being to aid the Contractor and expedite the work, he shall not be held responsible for the Contractor's errors, the result of which, should they occur, must be made good at the Contractor's expense. The Contractor shall make required changes in such drawings or diagrams and supply the Engineer with one correct copy. Any models or templates submitted shall be changed as reasonably required until satisfactory.

*Fires, Smoking, Etc.*—The Contractor shall not permit open fires to be lighted at any time in or dangerously near the building, and, after the roof is on, shall prohibit smoking within the building.

*Imperfect Construction.*—The Contractor shall notify the Engineer in writing if at any time he finds that any work or material that has or is being furnished by another Contractor in connection with his work is imperfect; and in case of his failure to give such notice, the Contractor shall be held to have accepted such work or materials, and all other existing conditions, and shall be responsible for any defects in his own work consequent thereon, or any change to his work made necessary by the future correcting of such defective work by other

Contractors, and shall not be relieved of the obligation of any warranty because of any such condition or imperfection.

*Imperfect Design.*—The Contractor shall notify the Engineer in writing if he thinks any part of the work as designed or constructed is unsafe or likely to become so, or unsuited to produce the intended results, and shall thereafter proceed with such work only on order from the Engineer.

*Lines and Levels.*—The Contractor shall establish all lines and levels necessary to the proper locating, laying out, and erecting of the work, in accordance with the Owner's survey and Engineer's drawings, and shall be responsible for their accuracy and maintenance. (See Schedule of Conditions of Contract, Section V.)

After the foundations have been completed and before the first tier of beams is set, the Contractor shall file with the Engineer a certificate from an approved surveyor showing that the building is located correctly according to the Owner's survey, and that the foundations, column bases, etc., are correct according to the drawings.

*Measuring Work in Place.*—The Contractor shall measure work already in place to insure the proper execution of subsequent work, or to assist the Engineer in making his drawings, and should any discrepancy between the executed work and the drawings be discovered, he shall report at once such discrepancy to the Engineer.

*Notifying Engineer.*—The Contractor shall bring to the attention of the Engineer any conditions pertaining to the site, the soil, the various portions of the work, whether executed by himself or by other Contractors, or to proposed work, or to laws and ordinances governing the work that should be known by the Engineer.

*Overloading Structure.*—The Contractor shall not permit any part of the structure to be loaded during construction with a weight greater than it is calculated to bear.

*Reports to Engineer.*—The Contractor shall furnish reports to the Engineer showing the status of the work at the building and in the shops, whenever so required, and in the manner directed.

*Signs.*—The Contractor shall not permit signs upon the building or premises, other than that of the General Contractor, except by the written permission of the Engineer.

*Storage Limits.*—The Contractor shall confine the storage of materials and the operations of his workmen to the reasonable limits indicated by the Owner or Engineer, and shall not unnecessarily encumber the premises with his materials.

## DISCUSSION

Mr. McLure.

NORMAN R. MCLURE, ASSOC. M. AM. SOC. C. E. (by letter).—In preparing estimates and bids on engineering work, chiefly in connection with the structural steel business, the writer has been continually confronted with the so-called "blanket clauses" in contracts and specifications. At first they were the cause of much anxiety, on account of the confusion and the uncertain element which they introduced, but later experience has proven them almost invariably an indication of ignorance or lack of understanding on the part of the engineer or architect responsible for their preparation.

In its most familiar form, such a clause follows an apparently mighty effort to cover everything with a statement that, if anything has been omitted from the plans or specifications which may be necessary "to make a complete and satisfactory job," or "to complete the work to the satisfaction of the architects," it is to be included in the bid, and constitute part of the contract; or, in other words, the writer of the specification practically says, "If I have omitted anything that I should have included, you (the contractor) must accept the responsibility for it." In addition to his business as a contractor, a bidder must also be a mind reader, or else practically start at the beginning and design the whole work, in order to ascertain whether the plans and data on which he is asked to bid, are complete.

It is obviously so unfair to solicit lump-sum bids on work not shown or specified, that instead of attempting to solve the riddle of what is really wanted, in cases of this sort, the writer now simply prepares his bid on the work clearly shown and specified, and states distinctly in the proposal, what is and what is not included. The basis for comparison of lump-sum bids prepared in this way, is, of course, unsatisfactory.

Architects seem to be the chief offenders, and, in the writer's experience, it is quite unusual to pick up a set of building plans and specifications prepared by an architect, and be able to discover, without much inquiry and investigation, just what is wanted. Engineers, apparently, are more careful, and make some effort to decide in their own minds just what they want before attempting to put it on paper. There is, however, infinite room for improvement in specification writing from the contractor's viewpoint; and as every structure has sufficient individuality to make it worthy of independent treatment, just so should every specification receive, in preparation, the intelligent thought of one who understands thoroughly the structure it describes.

"Standard" specifications, while useful, and almost indispensable as guides, should be used in that capacity only, and the representative contract clauses given by the author should prove, in that way, of great value in preparing any ordinary building contract.

Mr. Polleys.

WILLIAM V. POLLEYS, M. AM. SOC. C. E. (by letter).—The writer respectfully begs to take most decided exception to Mr. Bamford's statement that the lump-sum system of contracting is theoretically or practically the best, even in straight building operations where no unusual complications occur, and, further, he ventures the opinion that there are comparatively few building operations (of sufficient importance to justify a discussion before this Society) in which unforeseen complications to a greater or less extent do not arise.

With regard to Mr. Bamford's statement that the expense of work done by reputable "cost plus" contractors generally exceeds the cost under a lump-sum agreement covering identical work, because the owner is ill-advised or because the contractor, being sure of his profit, grows lax, or from any other cause, the writer desires to state that such has not been his experience, nor does he believe that such a statement is borne out by facts, nor by the experience of most men who have had intimate connection with both methods of work.

Getting ready for bids for lump-sum work is, in itself, a tedious and expensive operation, plans and specifications must be prepared providing for all contingencies which can be foreseen, but the usual result is that something has been overlooked or that the unexpected has happened.

Generally speaking, in the larger and more intelligently handled building operations, weight is given, in selecting the list of competitors, to their financial standing and to their reputation for experience and ability, but the competitors, nevertheless, are asked to gamble on the price of labor, material, on the state of the weather, on the state of mind of the person in charge, and on countless other matters entirely beyond their control, for a period of months, or possibly years, in advance.

The multitudinous clauses of the modern contract are to insure against human nature asserting itself if things go wrong. If things go as expected, or better, the builder, remembering that money is a good thing anyway, that his next bet may not be so fortunate, and that the owner, in endeavoring to tie him up, evidently expects him to untie himself if he can, proceeds to make every dollar possible under the circumstances, influenced, of course, by the desire to retain a good reputation, if it is not too expensive.

As long as the interests of owners and builders are thus diametrically opposed, the result is quite likely to be injurious to the operation in question, and, until human nature is greatly changed, will continue to be so, in spite of all the legal acumen that may be injected into a contract.

In the writer's opinion, the only remedy is to unite these clashing interests by some form of a "cost plus" contract. Under this ar-

Mr. Polleys.

rangement the interests of the owner and the builder are identical as far as possible.

The owner has merely to select some such contractor of known skill and reputation, tell him what he wants, ascertain the probable cost, with due allowance for unforeseen contingencies, and, if this is satisfactory, order the work to proceed.

He will get just what he orders and pays for, and will get it as cheaply, as quickly, and done as skillfully, as it can be obtained by any contract; not because the "cost plus" contractor is cast in a different mould from his "lump-sum" brother, but because his whole stock in trade is his reputation, and because his interests and those of the owners have become identical.

His employees are as skillful as any, have every incentive to do just the class of work that the owner wants, and to do it as cheaply as it can be done.

If the employee of a "lump-sum" contractor is careless or makes a mistake, it means the loss of a comparatively small sum of money, which is not of very great consequence; but, in the case of the "cost plus" contractor, it means a blow at his reputation which endangers his entire capital.

Dealing with reputable contractors who make a specialty of "cost plus" work, it makes no practical difference whether the "plus" be a percentage or a lump sum. Any difference in profit is too small to overcome in the slightest degree the overwhelming necessity on the part of the contractor to maintain an unblemished reputation.

The simpler the contract the better, any attempt to penalize or augment what should be but a fair compensation in the first place, by reason of variations from the estimate of cost or time, merely tends to divide the interests and invite the attendant evils.

There are so many other advantages attending the "cost plus" method of building that to emphasize them as they deserve exceeds the length intended for these remarks. Among them, however, there are: the expert advice available, both technical and business; elimination of pooling; the saving of time, in that work may be started as soon as a general plan has been formulated, leaving details to be worked out during progress; the fact that work may be advanced, retarded, suspended, or even abandoned, as exigencies may demand; plans may be changed; quantities may be increased or diminished; and all without that formidable bill of extras and damages, which is the "right bower" of the lump-sum contractor, and a disastrous weight to many owners.

It has been truly said that the bulwark of a contract is mutual confidence, and it may be added that the bulwark of mutual confidence is mutual interests.

Mr. Higgins.

CHARLES H. HIGGINS, ASSOC. M. AM. SOC. C. E. (by letter).—Mr. Bamford's able paper opens first of all the question of the desirability of a uniform contract, a subject which the American Institute of Architects has attempted in what is called the "Uniform Contract," but which, as far as the writer knows, has not been met by engineers, through this Society or otherwise, except in railroad contracts which agree in their general characteristics. Fairness is not the most striking feature of the latter, and they are not well adapted to the use of the consulting engineer in general practice, to which class, together with architects, the word, "Engineer," in Mr. Bamford's paper, seems to refer.

It may be accepted as axiomatic that "unfair contracts breed unfair contractors"—a case of the survival of the fittest.

It is desirable for all parties—the owner, the contractor, and the engineer—that the contract be fair, that contracting may be a business in the hands of responsible men rather than a game for gamblers.

Uniformity in the general clauses has a great advantage in itself, most directly to the contractor, but, through him, to all concerned. Imagine each engineer with a pet form of contract, all equally good, but differing in degree of responsibility, which necessarily affects the cost—an effect which may not be large relative to the total cost of the work, but is very large relative to the profit of the general contractor. This means that, in bidding on each piece of work, the contractor must study, not only the proposed construction in which he is an expert, but also the legal requirements, thus adding materially to the time and cost of making a proposal and reducing the number of close bidders. Of course, uniformity can be carried to the point of absurdity. A certain printed form of contract, recently signed, required the contractor to deliver a full-sized sample of each of the materials entering into the work at the architect's office before commencing operations. The "office" was a modern New York affair, well up in the air, and the contract was for driving 50-ft. piles. Here, clearly, the written words did not convey the intent of the contracting parties. There was not a "meeting of the minds," which constitutes a contract; and here is an advantage of certain general clauses in common use, which is what Mr. Bamford aims at. These clauses, of course, must conform with the law, and might differ slightly for use in different States; but, in the main, if such a uniform contract met with general acceptance, this fact and the usual manner of interpreting the clauses would be presumptive evidence of the intent, and thus influence the decisions of the courts, and further strengthen such a form of contract. A judge—and how much more so a jury—must be puzzled as to the intent when technical questions are involved and the parties to the contract cannot agree as to the meaning.

Mr. Higgins.

Of course, the defence of such a form of contract as is used by many railroad companies, drawn as it is almost wholly in the interest of one side, is that if the case gets before a jury, the talesmen's sympathies will be all on the side of the contractor as against the corporation, and, therefore, every effort must be made to keep it from a jury; but, if this be valid reasoning in the case of a railroad with a coterie of more or less dependent contractors, all familiar with the requirements and, what is more important, with the way the requirements are exacted, it does not by any means hold in the case of general building contracts carried out under an engineer.

"*Article I.*—The Contractor agrees to provide all materials and perform all the work for the * * *."

The writer would suggest adding in the foregoing, after the word "work," "and deliver complete," thus making the contract for a completed structure rather than for the furnishing of materials and labor. Decisions of the courts would seem to indicate the wisdom of this.

Perhaps first in importance is the arbitration clause, with all its legal pitfalls, and the possible requirement for better legislation which Mr. Bamford refers to, and which Wait treats so fully in his "Engineering and Architectural Jurisprudence," for this fixes the responsibility of the engineer, whether his decision is to be supreme until the matter is taken before the courts, or whether he can say, "This, gentlemen, is my decision; if either of you feels aggrieved, you have the privilege of calling in arbitrators." This would seem to be the strongest position for the engineer, for the owner is not always inclined to follow the advice of his engineer, and is often unfair because he is not thoroughly acquainted with the subject. The fact, stated by J. A. L. Waddell, M. Am. Soc. C. E., in "Specifications and Contracts", that "the law has decided that the losing party has still a right to appeal to the courts", should not be lost sight of. The courts seem to be jealous of their privileges in these matters.

*Liquidated Damages.*—This clause is a "thorn in the flesh" to a contractor, and yet it is often of the utmost importance to the owner that he shall know beforehand when he will receive the completed structure. The law will not allow a penalty, but will grant damages caused by delay. To the writer it seems wisest to state that time of completion is a consideration, and have the bidder name a time with his price. Then, before the contract is signed, have the owner and the contractor agree as to the amount per diem which the damage to the owner will amount to, in case of delay by the contractor. This should be written into the contract, with provision for retaining the sum from monies due.

*Drawings.*—Under this head it would seem well to provide a time, say one week, which would be allowed the engineer for the examination and return of drawings, with the provision that if he takes longer,

the contractor's time for completion shall be prolonged proportionately. Mr. Higgins.

One of the chief advantages an owner receives by retaining an engineer is the benefit of open and fair competition among contractors in the matter of price, and this is in direct proportion to the clearness and definiteness with which the subject for competition is presented. Therefore, it is the duty of engineers to work for all things which make for a more definite and fair relation between the owner, represented by his engineer, and the contractor. The writer joins Mr. Bamford in his plea for the development, by this Society, of uniform contract clauses, after careful consideration, and with an arrangement for revisions as new legislation and decisions by the courts may require.

W. G. WILKINS, M. AM. SOC. C. E.—The speaker has been very much interested in this paper. A building agreement or contract which will be just and equitable to both parties, and will not work hardship to either, or one in regard to which the courts, if appealed to, will decide that all its provisions are equitable and must be lived up to, is a very difficult thing for even a lawyer versed in all the technicalities of contract law to draw up, to say nothing of the difficulties it presents to the engineer or architect. During thirty years' private practice as an engineer in Pennsylvania, the speaker has found that up to the present time, there have been very few, if any, contracts which can not be broken for some cause or another. He is not familiar with the laws relating to contracts in New York State, but has no doubt that conditions in that respect are the same as in Pennsylvania. Mr. Wilkins.

When the speaker first began practice in Pittsburg, nearly all contracts provided that the contractor must forfeit a certain amount per day, or a fixed sum, if the work was not completed in the specified time. It was not long before the courts decided that such a clause was illegal, unless a bonus was provided if the work was finished in less than the specified time. In order to avoid the possibility of having to pay bonuses to contractors, the scheme of introducing a "liquidated" damage clause into the contract was evolved, but it was not long before the courts decided that before the owner of a building could recover so-called "liquidated" damages from a contractor, the latter could take the owner into court, and unless he could prove actual damage by reason of the contractor being behind time in the completion of the work, he (the owner) could not recover damages. Even if the owner could prove actual damages, it might be possible for the contractor to avoid payment by proving that changes had been made in the contract after it was signed and while the work was in progress. The speaker knows of one case where a large firm took a contract for building a manufacturing plant from plans furnished by the con-

Mr. Wilkins.

tractor himself. The contract specified the time required for the completion of the work, and also contained a liquidated damage clause inserted by the attorney of the company for which the plant was to be built. After the work was well under way the contractor himself suggested certain changes which he assured the owners would not only better the work, but also lessen the time required for its completion, and on these representations the owners consented to the changes. Instead of hastening the completion of the work, it was not finished until several months after the time specified had expired. The owners of the plant, therefore, deducted from the final estimate the amount specified in the contract for liquidated damages. The contractor brought suit for the amount deducted, and alleged that the contract was broken by reason of the changes in the plans, and, although these changes had been made at his own suggestion, the court ordered the jury to award him the full amount of his claim.

The speaker has also been much interested in the author's remarks on arbitration. He does not believe, however, that a contract can be drawn up containing any arbitration clause which can be made absolutely binding on the parties to a building contract unless the existing laws are changed, and it is doubtful whether the legislature of any State could, under its constitution, take away the right of the courts to review a contract. It would certainly relieve the courts of a great deal of work, and the parties to a disputed contract would save a great deal in the way of expensive litigation, if such laws could be made.

In the past nearly all building contracts in the State of Pennsylvania have contained an arbitration clause similar to the following:

"It is further agreed that any and all disputes or differences of any and every kind, growing out of or in connection with this contract, either as to its terms or the character or quantity or manner of performance of the work, which may arise between the parties thereto, shall be referred to the Engineer (or Architect) for decision, and the decision of said Engineer (or Architect) shall be final and conclusive, and each and every one of said parties do hereby waive any right of action, suit or suits, or other remedy at law or otherwise, by virtue of said covenants, so that the decision of said Engineer (or Architect) shall be in the nature of an award, and shall be final and conclusive on the rights of said parties."

The Pennsylvania courts have always frowned on such clauses, and have looked on them as taking away their rights to review a contract and as depriving the parties to the contract of their rights to a judicial review and the award of the arbitrator. At the 1907 Session of the Legislature, an Act was passed, which contained the following clause:

"Providing that the jurisdiction of the Courts shall not be ousted by a provision in a contract that an award or an appraisement by an Engineer, Architect, or other person shall be final or conclusive, or

that a certificate of an Engineer, Architect, or other person shall be a condition precedent to maintaining an action upon such contract; and that any controversy arising on a contract containing such a provision shall be determined in due course of law, with the same effect as if such provisions were not in such contract; contracts with municipal or other corporations, invested with the privilege of taking private property for public use, excepted." Mr. Wilkins.

Even if such clauses were held by the courts to be binding and without appeal, the speaker has believed for some time that all disputes should not be referred to the engineer or architect, and in discussing the matter with brother engineers, has found that most of them agree with him, that unless especially agreed on by both parties to the contract, the engineer or architect should only be the arbitrator as far as the character of the workmanship and the quantities or qualities of the materials are concerned. These are matters with which engineers or architects would be more familiar than any court or outside arbitrator; but there are other disputes which might arise concerning the terms of the contract, which the engineer or architect, being in a certain sense the employee of one of the parties, should not, in justice to himself, be called on to decide, unless by a special agreement of both parties. With this idea in view, the speaker drew up and submitted to his attorney the following clause, which the latter approved:

"It is further agreed that in all other questions or disputes that may arise, between the parties hereto, touching the interpretation of the contract and specifications, other than those affecting the character of the workmanship, or the character, quantities, and qualities of the material, the matter may be referred to the Engineer for a decision, by the parties hereto, with the understanding and agreement that if said matters are so referred to the Engineer, the decision of said Engineer shall be final and conclusive and binding upon both parties hereto and without appeal. If, however, such disputes are not mutually referred to the Engineer for decision, both parties to this contract hereby agree to refer such disputes to three disinterested arbitrators, one to be appointed by the party of the first part, one by the party of the second part, these two arbitrators shall select a third, and the decision of a majority of these arbitrators shall be final and conclusive and binding upon both parties to this contract, and the parties hereto agree to accept such decision and waive every right of action, suit or suits, or other remedy at law or otherwise, by virtue of these covenants."

When this clause was written the speaker thought he had an arbitration clause that was just and equitable to all parties to the contract, including the engineer and architect, but it is nullified by the Act of the Legislature previously referred to, so far at least as making the decision of the arbitrator final, no matter whether the engineer, or architect, or disinterested arbitrators have made the

Mr. Wilkins. award, unless one of the parties to the contract possesses the right of eminent domain. The speaker, therefore, still believes it to be a practical impossibility to draw up a building contract, which, like a great many wills, cannot be broken for some cause or other.

Mr. Boring. WILLIAM A. BORING, ESQ.*—The American Institute of Architects, under the presidency of Mr. Day, thought it would be a good idea to standardize the practice of architecture, from the point of view of contact with the builder, and for that purpose a committee of five was appointed to evolve the general conditions of a specification to be used by architects. That was about three years ago, and this committee has been working on the document ever since. It has at last completed the "General Conditions of the Contract," as it is called, which, in reality, is a sort of code of procedure. This is about to be published and distributed, or put on sale, in the same manner as the "Uniform Contract" which is in such general use. Of course, it will have to be modified more or less by private practitioners.

The committee began by obtaining specifications from the leading architects of the United States, dissecting and analyzing them, and, after determining the main questions, finding out how these were solved by the different practitioners. It then endeavored to improve on the form of the matter, adding such new ideas as were suggested by a study of the subject in detail.

After the committee had worked on this for more than two years, Mr. Day discovered, in the Annuary of the Royal Institute of British Architects, a document which represented the experience of some thirty years of practice and study in England, which corresponded very nearly to the ideas held by the committee of the American Institute. This document was dissected and compared with the work of the committee, and it was found that the latter had covered nearly every subject. The committee felt flattered to find that it had covered the ground in almost the same way as the British architects.

The American document, of course, applies more especially to practice in the United States, where the system of quantity surveying does not obtain, and there are not the same legal restrictions as those governing the practice of architecture in England.

The speaker is bound to state that when this document is sent out, it will be criticized voluminously. It will not suit any one practitioner in all its phases, but if architects knew how long a time had been spent over each subject, and how it was taken up again and again for comparison with all the different sources of information, they would probably not decide as they will when they print their specifications for their own particular practice.

It is impossible, and it always will be impossible, in an open meeting, to discuss the details of contracts or specifications. That must be

* Architect.

done by committees, by a few men together, and after consulting the various authorities; and even when a final draft is agreed on, it will be more or less of a compromise, as any such document must be. It is something that will be varied according to the circumstances of each case. Mr. Boring.

Too often the client makes the mistake of thinking that perfect specifications make a perfect building. He engages his architect, and thinks it does not make much difference who the contractor is, for as long as he has a good plan and specifications, the contract is bound to produce a building as described.

When a client advances this idea, the speaker tries to illustrate the position by saying: "Suppose you wanted a fine watch, and you made a very strong contract with a shoemaker to make you such a watch. Then you go down to Maiden Lane and get the finest watchmaker in New York to superintend the job. Now, what will you get as a result, a watch or a pair of shoes?" That is about the effect of documents when reliance on them alone is the safeguard of a building operation.

The erection of a building according to a plan and specification is a question between men: on the part of the contractor as to ability and integrity, and on the part of the architect to describe clearly what he intends the building to be. Of course, the position of architects differs slightly from that of engineers. In addition to the protective side of the contract and the specifications, architects have to take care of the æsthetic side. This involves questions which cannot always be described in specifications, and the result will depend largely on the individuality of the man who is to produce the building; whereas, for engineering projects, specifications can give more nearly exact physical descriptions.

Architects have to take care of Government work, in which the protective element is much more strongly emphasized than in private practice, because the position that every engineer or architect is bound to take when he lets a contract on Government work is that the contractor is trying to beat the Government in some way or another, and his documents all presuppose that the contractor is more or less dishonest, whereas, in private practice, he deals with men known to the owner, and there the owner and the builder meet on more of a common ground, and more is entrusted to the contractor. The private owner is also more interested in the case. He does not employ $2 000 men to decide $5 000 questions, as is done in Government work.

The document prepared by the American Institute of Architects, called the General Conditions of the Contract, the Notice to Bidders, Articles of Agreement, Form of Bid, and a Form of Bond, is complete up to a certain point, and is to be printed. It would be a good idea for this Society to appoint a like committee, that is, if the

Mr. Boring. Society is sincerely interested from the same standpoint, and the American Institute of Architects would be glad to have its criticism on this document. There will be something to base criticism on, and the Committee will find it a long and tedious, but not an unpleasant, task. The American Institute of Architects will be glad to co-operate with such a committee.

Mr. Wait. J. C. WAIT, M. AM. SOC. C. E.—This is a subject in which the speaker has been interested for many years, and he would not concede that a contract cannot be drawn which cannot be broken. Engineers intend to draw contracts which will hold. If anybody doubts it, let them take a few cases against the City of New York and see what has happened. Mr. Bamford is to be commended for this most excellent paper. It would have cost the Society a great deal in fees to have employed a lawyer to do the work which he has done gratis. He has presented in this paper something which the speaker did not appreciate, until he was informed that this form of contract is the result of some twenty-eight years of work by a committee of the Royal Institute of Architects, and that he has given his elaboration and modification of it.

The speaker would like to see the contract finally adopted by the Royal Institute published with this paper, in order to compare the author's amendments with it, and with that portion which was approved and finally accepted by the Institute of Builders and the Federation of Builders.

For a layman to prepare a paper on a legal subject and to show so much familiarity with it is surprising. The speaker has made the subject of contracts a specialty for the last twenty years. He has talked with Mr. Bamford about building contracts, and finds him well informed on the subject, and also with the breakers which are met in the preparation and performance of contracts.

Some of the questions which present themselves in this contract will be discussed by the speaker. One is that the architect's decisions may be reviewed in full after the work is completed, if either the contractor or the owner is not satisfied with them. That seems to be unfortunate, because architects may make decisions with which the parties may be well satisfied at the time. If they can tear up the ground behind them, and make a case in court, it will be found that the contractor or the owner will disagree and take up for review many things which he never would have thought of, but considered as settled. After a matter has been decided by the architect, and the parties have not raised any dispute about it at the time, it should be considered as *res judicata*, or as an account stated and settled.

The trouble with the arbitration clause is that it has no binding effect whatever. The speaker is not sure that he should mention this, because the evident purpose of the Royal Institute of Architects in

Mr. Wait.

inserting that arbitration clause was not that it would bind the parties, but that it would act as a brake on the architect or engineer, and make him more careful of his decision, fearing an appeal. Neither party need live up to it, nor carry out its provisions. That being so, what is the use of inserting an arbitration clause, when either party may refuse to abide by it? The trouble is that nobody has found a means, except by putting up a bond, to make either party abide by it, because this Government guarantees to every citizen the right to the determination of his troubles in Court, and the Courts state that it is against the policy of the law to allow a man to preclude himself from going into Court.

A contractor, however, is required to fulfill the conditions of his contract. If a man makes a contract and then breaks it, he must stand in damages. In several cases the speaker has declared in damages which resulted from the refusal of the owner to carry out his arbitration clause, and he has shown that the Court procedure cost so much for expert witnesses, lawyers' fees, and other expenses, and that, therefore, it ought to be recovered in damages. The judges in every instance have smiled and put it aside.

Of course, one can draw bonds and make them conditioned on the parties carrying out the arbitration clause, and, if they do not, the bond will be valid and binding, and, if they do, it will become null and void.

There is no doubt that arbitrations are the best and most wholesome way of deciding disputes in building matters, if they are carried out. The average trial of a building case before a referee costs from $2 000 to $6 000, certainly a very expensive operation. A high-class referee in the City of New York costs from $20 to $25 per hour; that means the best, which is what is wanted if the case involves $60 000 or $100 000.

These references usually occupy one day a week, and extend from one to five years, and, after calculating the cost of attorneys' fees and the services of experts at from $100 to $200 per day, one has an idea of what the contractor may lose. The lawyer and the referee profit, and the owner and the builder lose—sometimes more than they would if they had abandoned their claims.

If one could have an arbitration, not of three members, but consisting of one member, a high-class technical man familiar with the subject, agreed on or appointed by the Presidents of the American Society of Civil Engineers and the American Institute of Architects, selecting men who are retired architects or engineers, who are not affected by business competition, who are old enough not to be swayed by commercial operations, and who would be real judges and would administer justice, then a solution of this difficult problem might be attained.

Mr. Wait.

There would be one arbitrator to pay, instead of three, and better satisfaction would be obtained. Better results would be reached than some which members of this Society and members of the Institute of Architects have seen obtained in the average building case tried before a jury, whose ignorance is displayed at every step of the trial.

There are certain things in this contract to which the speaker would call attention. It states that contractors shall indemnify and save harmless the owner from any injury or damage caused by or "alleged to have been caused by" any act or omission of the contractor. It reserves the right to retain money to meet any claim that is filed. The result is that if a contractor of the City of New York has any difference with his employees, or anybody has an imaginary grievance, he immediately files a lien with the Comptroller, and the Comptroller immediately makes that an excuse for holding up his money, often without any sense or reason. As an illustration: The lien laws of the State of New York state that a person shall have a lien for materials actually delivered on the work and incorporated into it, and for labor actually spent on the work. For the anchorage of the Williamsburg Bridge certain stone was ordered from a quarry. The stone was quarried, cut, and stacked up in the yard at Cobleskill, N. Y. It was never delivered to the work, and was never made any part of it, and yet the Receiver of the quarry company filed a lien for $26 000 on account of that material. The Comptroller, by advice of the Corporation Counsel, held up the money for from one to two years, to the great detriment and damage of the contractor. Under the author's contract, claims made under any injury "alleged to have been caused" by an act of the contractor might be a powerful weapon in the hands of a hateful or insolvent owner. He might get his neighbor to allege that he was damaged, and make claim, and thus give the owner sufficient excuse for holding up the monies otherwise due and owing.

There are a number of things of that kind in this contract which perhaps are more properly the subject of written discussion, but the speaker would impress upon the Society what seems to him to be the necessity for a standard contract. The standard contract, known as a "Uniform Contract," recommended by the Institute of Architects and the National Builders, is a very poor document.

What the Committee of the Institute of Architects will present soon, after several years' work, cannot be told, but this Society, in collaboration with the Institute or by itself alone, could devise a standard contract. As a foundation there has been presented in this paper the substance of a document which cost the Royal Institute of Architects and Institute of Builders some twenty-eight years of work. On the whole it is a very good contract. It is a better contract than would be obtained from the average lawyer, and the speaker recommends its use, with some slight modifications.

Mr. Wait.

As an illustration of what might result and a use that could be made of such a contract, two or three instances which have come to the speaker's notice may be cited: The new Manhattan Bridge was built in less time than any bridge of its character or size, and with no friction whatever. All the contracts were prepared under the speaker's direction. These contracts, for the structural steel, the wires, cables, and suspenders, and for their erection, comprised some four or five pages each. The contract with the American Bridge Company for the steelwork for the Madison Avenue Bridge comprised one page of typewriting; the contract for the steelwork for the approaches of the new Manhattan Bridge comprised one page, and they were approved by the attorneys of the respective parties, and there has been no friction and no trouble.

This can be explained by the fact that the City contract was a foundation or reference. These contracts were merely indentures binding the parties, and by reference embodied the City contract.

Now, if there was a standard contract, whether printed or merely filed with this Society and the Institute of Architects, the statement could be made, in the fewest words, comprising one page of typewriting, that both parties would be bound by it, and then it could be embodied by reference, and the contracts would be as brief as possible. For that practice this contract is specially adapted. Having the contract, the conditions and specifications, which might be called a code, and then the plans, these can be embodied in the contract without rewriting them. They could be printed and put in the hands of every member of this Society.

That would save attorney's fees and great delays. Perhaps the speaker should not be arguing this way, in view of his dual professional position; but it would nevertheless save a great deal of time in the preparation of contracts by the engineer and for owners. In view of the way contracts are closed, projects often fail and a fine job is lost, because the contract is not ready and is not signed before the job gets cold.

With a standard contract and with means of closing it promptly, and with the further feeling that it is a good contract and one which will hold, engineers would close their contracts on the spot, and would save themselves some fees and some projects, which sometimes get away from them owing to changed financial conditions and other happenings in Wall or Broad Streets.

Mr. Bowman.

W. L. Bowman, Esq.—There is one section in the proposed building agreement which has been especially called to the speaker's attention. This is Section XXIV, regarding the extension of time to the contractor under certain conditions and circumstances. Experience has shown that this does not afford proper protection for the contractor.

Mr Bowman.

Most contracts now in use and the form of contract given in this paper protect the owner thoroughly, and those who represent so largely contractors and sub-contractors are naturally most interested in those clauses which affect their protection. The result of this extension of time, granted under Section XXIV, was well illustrated by one of the speaker's clients, who stated that "this would be equivalent to contracting with a man to furnish ice in winter and then giving him an extension of time so that he would have to cut the ice in the summer." Take a specific example in the speaker's experience. A quarryman contracts with an owner to furnish and lay certain granite by specified dates, the contract having been entered into at such a time that, provided the work was done rapidly and with a full force, all the quarrying could be completed before winter, and the setting done in the late spring. Suppose then that the architect or engineer does not furnish the detailed plans and models necessary for the quarrying and cutting, with the result that the work, instead of being carried on with a large force working daily, has to be performed as the details are received, with a force of men varying from 10 to 100 per day, and the quarrying, cutting, and setting have to be done in cold and freezing weather; then one can realize how, under this contract and under Section XXIV, the quarryman might lose thousands of dollars, and his only remedy would be an extension of time to complete his contract. This conclusion—that the extension of time would be exclusive—is drawn from the fact, that, although there is some difference of opinion on the subject, depending chiefly on the special circumstances of the case, the laws of the State of New York and of many other States seem to hold, that where, in such a contract, an extension of time is specifically granted, such extension provides the exclusive remedy which the contractor has for his damages. That, certainly, is not fair to the contractor, and, in the speaker's opinion, it would seem that such a clause works more hardship than good. It would seem to be only proper to modify this clause and make it more in conformity with Section XXIII, and provide for damages to the contractor, so as to make his damages recoverable for delays, etc., equivalent to those therein granted to the owner. These damages, however, should be limited to those caused to the contractor or sub-contractor by architects, engineers, sub-contractors, etc., who are the agents or direct employees of the owner.

There is one other situation which has been forcibly brought to the speaker's attention, and that is, if a uniform contract is determined on, sub-contractors must be careful with regard to its provisions and see that they are protected against the general contractor to the same extent as the latter will be against the owner.

Suppose that a sub-contractor enters into a contract with a general contractor and signs a uniform contract containing a clause stating that the architects or engineers shall act, for the purposes of the con-

tract, as agents of the owner. Then, if the architects or engineers should fail to supply the plans or specifications on time, and the sub-contractor should thereby be damaged, he could have no recovery against the general contractor because of the specific provision in the contract that these defaulting parties were the agents of the owner, and it seems to be very uncertain as to whether he would have any rights as against the owner. This decision has been made very lately by one of the Appellate Courts, the result being that the sub-contractor, who is usually the least able to bear the burden of such losses, must stand them, and the owner, engineer, or general contractor, whoever may be to blame, receives the benefit without being liable for the damages which he may have caused. Mr. Bowman.

These two matters have been brought home so forcibly by experience that it has only seemed fair to call attention to them at this time. In conclusion, the speaker desires to commend Mr. Bamford on his excellent work, which, with a few changes of language (using American instead of English terms), will provide a much better contract than any in general use to-day among builders and engineers.

CHARLES A. RUGGLES, ASSOC. M. AM. SOC. C. E.—The engineer's, the architect's, the owner's, and the attorney's views of a uniform and standard building agreement have been stated, and it may be interesting to have the contractor's as well, for although by many they are considered an evil, it may be conceded that they are necessary or convenient, and make for economy for the owner, engineer, and architect; they are also a source of revenue to the attorney, and therefore, are to be considered as a factor in architectural and engineering work, and as the other party in such contracts or agreements. An architect is, by definition, a master builder; an engineer, as defined by Wellington, is one who can do for one dollar as much as a —— fool can do for two; an attorney's highest achievement is to keep his client out of court and trouble; a structural contractor is a combination of both engineer and architect, or he is nothing; therefore, owner, architect, engineer, attorney, and contractor should act and re-act with business equity, harmony, and mutuality in a "meeting of minds." Mr. Ruggles.

Mr. Bamford's work is admirable, and, as a means to an end, his paper will often be referred to, but it may be conceded that the form which he proposes carries too great a load, goes too far afield, and leads into temptation and court, rather than to an adjustment and settlement based on demonstrable facts which no sane man will waive aside and seek instead his constitutional day in court. It may be conceded, too, that one cannot be kept from court by a contract, that arbitration is a name only, is not enforceable, and, when accepted, is the decision of one man without judicial temperament or training in the correlation of law and facts, so that the result of most arbitrations is only an expensive compromise.

Mr. Ruggles.

It may also be postulated that he who is his own attorney has a fool for a client, and from this the corollary that no uniform form of building agreement can ever be drafted which will fit any or all structures or work; but if adequate plans, and complete and equitable specifications—free from the club clauses which Mr. Bamford so aptly characterizes—are used as the instruments of service and the basis of the agreement, it may be approximated. When plans and specifications which leave little or nothing for conjecture are offered for contract, competition, if asked, will be keen, and prices low, with no fear of court or distrust of arbitration; and minds will meet in a simple statement of the work to be done, the time to do it in, the amount to be paid, the time and method of payment, and the method of voidance for a breach; and such a contract will not be the paper-covered hoop through which an able attorney can drive his legal team. If the engineer and architect will do their part, the owner and his attorney will have little difficulty in enforcing the contractor's part.

Owner, architect, engineer, attorney, and contractor must share alike the burden of creating the necessity for more equitable contractual relations, and none other can exist or long be maintained. The owner is responsible for demanding the inequitable and "club-clause" contract; the attorney, for preparing the inequitable but legal contract; the engineer and architect, for preparing or copying contract forms which are either inequitable or illegal, often both, and for preparing specifications with vague and club clauses to cover his or their carelessness, oversight, or lack of experience, or to please clients. The contractor should refuse to sign a contract or accept specifications which force him to take a gambler's chance.

The following contract clauses, quoted from live contracts, might be viewed with distrust and conceded to be inequitable and perhaps illegal:

"All extra work required to be done and materials to be furnished to the owner by the contractor shall be furnished by the sub-contractor at exactly the same prices as shall be received by the contractor." "No allowance by reason of extra work shall be demandable by the sub-contractor, saving so far as the same may be conceded by the owner." "Any right of action for any cause arising in or out of the contract in any court of law or equity is expressly waived by the contractor." "It is expressly agreed and stipulated by and between the parties hereto that all right of lien for labor or material is expressly waived, and that no lien for any cause be filed." A prime favorite is: "It is expressly agreed that all laws, ordinances, and municipal regulations are, and become, a part of this contract, and should they [*sic*] require additional material or change in quality or both, it shall be furnished by the contractor without additional charge." Another favorite is: "The contractor agrees to furnish proper legal and safe foundation, if those shown are not such [*sic*], without additional cost to owner."

Mr. Ruggles.

These two last clauses are pathetic, if not absurd, and none but a Lloyds insurance company could safely sign a contract containing them.

The following are a few of the objectionable "club clauses" which the speaker remembers; they may be of interest:

"It is the intention of these plans and specifications to comprehend a complete building in every respect and in accordance with the requirements of the owner, whether particularly shown or specified or not, without additional cost to the owner." A favorite is: "The plans and specifications are intended to co-operate, and anything not shown but specified, or specified and not shown, or neither [*sic*], if required by the owner or architect, is to be supplied as though both shown and specified."

A large corporation makes the contractor wonder if he is the other party or the victim by asking his signature to a contract containing this clause: "For the purpose of this contract, the architect is to act as the agent of the owner." Then, in the specifications, which are made a part of the contract, this is found: "The decision of the architect, as to the extent or quality of the work or materials or the cost of additions or deductions, shall be final, and there shall be no appeal from such decision."

It might be conceded, too, that there is another force which engenders strife and litigation from building contracts, namely, the penalty or liquidated damage clause for delays, instead of an adjustment on the proper measure of damage. In reference to this matter, some popular textbooks on building jurisprudence fail by stating rules of law which are not sustained by the courts in leading cases. These carelessly or too broadly stated rules often lead the owner, architect, engineer, and contractor into error and litigation with a case which has so little defense or merit that careful counsel would advise settlement. To illustrate this contention, assume a contract with a liquidated damage clause, and that the owner has ordered extra and additional work after the time for completing the contract has expired; that the owner has made payments, on the certificates of the architect, after the time for completing the contract has expired; that the owner has taken possession of the building on completion, some months after the contract time for delivery, and is enjoying the benefits of the same, all of which acts on his part were without protest, but that, in settlement, he retains the amount of the per diem penalty. The contractor, if he reads from the rules with citations given in one of the much-used text books, can form a strong theory of perfect defense for refusing to allow the penalty, on the grounds that the owner has waived his right for damage or forfeiture.

Mr. Ruggles.

The book states:

"It has been held that allowing the contractor to continue the work as if under the contract, after the time limit had expired and without claiming the forfeiture which might have been exacted, was a waiver of the right to such forfeiture. * * * Acceptance of work may be held a waiver of right to demand damages. * * * Requests or orders to the contractor to go on with the work, or to complete it, have been held to amount to a waiver of the clause for the liquidated damages. The making of payments after default of contractor without objection, after the time for completion has passed, is a waiver of any claim for damages for such failure to complete in time."

This is misleading but gracious language to the contractor with a forfeiture to defend, but he will be wise if he avoids litigation with no stronger defense than might be gathered from the language of the book, for before any building or engineering operation is finally accepted and paid for, the owner, without doubt, gives color to such a defense by doing any or all of the before mentioned things, and a careful examination of authorities and decisions of the New York courts gives color to the conclusion that none or all of the acts cited constitute a waiver of a claim for damage.

Mr. Lowinson.

OSCAR LOWINSON, ASSOC. M. AM. SOC. C. E.—Those who have had considerable experience in courts of law, or in arbitration cases, know that a court will frequently change the reasoning of a contract to suit what it thinks should have been the condition of the minds of the parties at the time the contract was signed, and frequently those clauses which cover lack of description are adversely ruled on by the court, or so as to assume that if the architect or engineer has omitted them, it was due to his lack of knowledge, and, in view of his not knowing what was wanted, the contractor is given the benefit of any doubt.

Some years ago the speaker was engaged as an expert on a case in which he represented the owner, suit having been brought by a contractor who had defaulted and had been taken off the job. The trial lasted about three weeks, and the decision was quite an experience, because it allowed the contractor considerably more money than it was thought would be allowed by any court of law. Two years later, the speaker met the judge (who had then retired from the bench), and asked him why it was that, in this case, in view of the evidence, he had given that decision. His reply was that, although possibly by keeping strictly within the letter of the law and the contract, the contractor would not have been entitled to the amount allowed, he felt that it was his business (and it is also the custom in the courts) to try to put himself in the position which the owner and the contractor were at the time the contract was signed, and that if the architect was not familiar with the details of the work he intended to have done, and had inserted in the contract clauses which he intended to use as clubs, the courts looked with disfavor on such practice.

Mr. Lowinson.

As a result of several decisions of this kind, the speaker is careful to draw contracts so that they will contain as little as possible, and to make specifications as complete as possible, and, where there is any doubt, to set aside considerable sums for matters which have not been thoroughly covered. All this is included in the provisional clauses in the contract proposed by Mr. Bamford, and, with certain variations, might very well be adopted.

In the issuance of the certificate for payment, the author requires the architect or engineer to do certain legal work; as a practising professional, the speaker would not like to do this. For instance, on the evidence of any claim or lien at the time of the issuance of the certificate, the engineer or architect shall withhold from this certificate an amount sufficient to indemnify the owner in case the lien be shown to be well founded. This is a matter which should be left to the owner. Possibly the speaker is wrong, as he is not a lawyer; but his custom has been to issue a certificate, which the contractor presents with a warranty from the County Clerk showing that there are no liens against the property; or, the owner has a search made, and it is he, and not the architect or the engineer, who determines the question of withholding the money. It puts the architect or the engineer in the position of being compelled to decide questions of law instead of matters of construction.

Mr. Thurston.

E. T. THURSTON, Jr., ASSOC. M. AM. SOC. C. E. (by letter).—The writer has reviewed with interest the author's attempt to realize an ideal and universal form of complete contract, and, while questioning the practicability of such a contract, can see naught but good to come from an extended discussion of the whole question, based on as good a model as that advanced in the paper. The trouble with too many contracts and specifications is that they are products of a combination of ignorance, egotism, and despotism. Employed as an expert to design and supervise the construction of a proposed building, the average architect, though possibly unassailable as an artist, and possessing a good fund of general knowledge as to finish and equipment, is densely ignorant of details of structure and equipment, and instead of, in his turn, employing qualified experts to assist him, he imposes on the confidence of his client by deliberately attempting to design and specify the work himself, or by accepting the proffered free services of an "expert" (with an ulterior motive), who proceeds to fix the specifications against competition and to hold up the general contractor. Experience has taught him that in order to protect himself from the results of his ignorance and cupidity, it is necessary to have recourse to ambiguities and blanket clauses, to the end that he may force the contractor to do his pleasure regardless of the apparent intent of the adopted plans and specifications. Inasmuch as there are generally several among the contractors bidding on each job, who are

Mr. Thurston.

so anxious to get the work that they will sign anything, the ambitious contractor falls an easy victim to the take-it-as-it-is-or-leave-it ultimatum of the architect. This paper, therefore, is most opportune.

A rapid reading of the form of Agreement and Schedule of Conditions of Contract submitted impresses one with its unnecessary verbosity, greatly detracting from its ready intelligibility to the average contractor. The writer believes that one of the most needed improvements in forms of contract is along the line of simplicity. The Courts will maintain the validity and sufficiency of a much simpler form than the lawyers seem willing to give. Furthermore, the writer fails to see the disadvantage of incorporating what the author calls the "Schedule of Conditions of Contract" in the contract, over the signatures of the parties thereto.

Referring to Article II of the form of Agreement, the writer believes that a contractor, unless working under a satisfactory bonus-and-forfeit arrangement, should be allowed a definite number of working days in which to complete the specified work, and that the contract should define clearly what is intended to be understood as a working day. It is not enough to define a working day as one on which it is possible to work, for while it may be possible to do some work, the prevailing conditions may be such that the operation of the contractor's force may be very greatly curtailed; for example, a succession of damp days may greatly retard the progress of the interior finish of a building. The writer suggests the following wording for Article II:

"*Article II.*—The Contractor agrees to complete the works in .... working days, provided, however, that should the Engineer decide that certain departments of the work which the Contractor is ready and desires to proceed with, should, for any reason, not attributable to act or neglect of the Contractor, but due solely to circumstances beyond his control, be deferred, and should this impose a hardship on the Contractor, the latter shall be allowed such extension of the aforesaid period of time as the Engineer may deem justly compensatory therefor, it being understood that the Contractor must make written demand on the Engineer for such extension, and that the Engineer's decision shall be definitive (subject to arbitration)."

As an alternative to the author's clause covering the question of the time element and damages for delay, the writer has the following to suggest, in which he would recognize the value of the contractor's time as well as that of the owner:

"It is agreed by the Contractor and the Owner that time shall be of the essence of this contract. The Contractor agrees that he will reimburse the Owner in liquidated damages for any delay in the completion of the works beyond the agreed time, by paying to the Owner damages not to exceed $..... for each and every calendar day's delay so caused, said damages to cover the cost of all extra inspection

Mr. Thurston.

and supervision, loss of rents, and all other expenses, suffered by the Owner on account of delay in completing the works, and the Owner shall be entitled to retain, from the amount otherwise to become due the Contractor, an amount sufficient to cover the estimated damages. The Owner agrees to reimburse the Contractor, in liquidated damages, for any delay in the completion of the works caused by him, covering the extra expense of superintendence, interest charges, tying up of plant, and all other expenses incidental to such delay, by payment to him, at the time that his final payment under this contract becomes due, a sum not to exceed $..... for each and every calendar day of delay so caused."

Article III, as suggested by the author, does not fit California conditions, inasmuch as the State Lien Law declares that at least 25% of the entire contract price must be retained for a period of 35 days after the completion and acceptance of the works. In private contracts there is seldom any further attempt made to insure the proper completion of the works by retention of any additional amount from the contractor's payment, but in public contracts, although the Lien Law does not apply, a bond in excess of 50% of the contract price is often exacted, and, in the case of some work in San Francisco, the progress payments are limited to 50% of the value of the work done, the latter being a noteworthy instance of an attempt to exclude contractors of limited capital.

Article IV seems to be excellent in form, but it would appear that the owner should be afforded some protection against criminal negligence or collusion, and the writer would suggest that the following be added to the clause as submitted:

"unless, in the opinion of the Arbitrators, said decision, approval, or direction was given in collusion with the Contractor, or otherwise in disregard of the provisions of the plans, specifications, and contract and the exigencies of the situation, in which case the disputed decision shall be reviewed and the matter finally decided by the Arbitrators."

In Section III, of the "Schedule of Conditions of Contract," the writer suggests that the second sentence be made to read as follows:

"Such copies of all drawings and specifications as may be necessary to the proper execution of the works shall be furnished by the Engineer free of cost to the Contractor for his own use."

The three sets allowed by the author will seldom satisfy the requirements of sub-contract work.

As a criticism of Section IV, which follows the customary practice, the writer believes that in all cases the owner should furnish and pay for the building permit.

With regard to Section VII, the final sentence of which reads, "No sub-contractors to whom the Engineer has made written objection, shall be employed, and the Contractor shall assume full responsibility

Mr. Thurston.

for all his sub-contractors", the writer believes that inasmuch as the contract holds the original contractor solely responsible for all the works, including the parts sub-contracted, it is wholly unjust to place any restrictions whatever on the contractor regarding the sub-letting of work, it being entirely reasonable, however, to require the submission by the contractor, prior to the signing of the contract, of a list of sub-contractors from among whom he proposes to make his choice.

For Section IX, part of which reads, "The Contractor shall also furnish duplicate labelled samples of materials and workmanship for the Engineer's approval, etc.", the writer would suggest the following wording as more specific: "The Contractor shall also, as required, furnish duplicate labelled samples of material and workmanship for the Engineer's approval, etc."

The writer considers Section XII superfluous, in view of the fact that the contract recognizes only the engineer in authority on the building.

In Section XIII, the writer would be inclined to omit the proviso penalizing a contractor for covering up work in contravention of the engineer's instructions, if, ultimately, it be found to be in accordance with the drawings and specifications. The ignorant, vacillating, but autocratic engineer often imposes great hardships on the well-meaning contractor.

In Section XV, relating to defective work, which reads: "Any defects, shrinkage, or other faults which may appear within ..... months from the completion of the works, and, in the opinion of the Engineer, arising from materials or workmanship not in accordance with the Drawings and Specifications or the instructions of the Engineer, or any damage to pointing by frost, appearing within the like period, shall, upon the direction in writing of the Engineer, and within such reasonable time as shall be specified therein, be amended and made good by the Contractor at his own expense, unless the Engineer shall decide that he ought to be paid for the same, etc.," the writer would eliminate the phrase "or any damage to pointing by frost, appearing within the like period" as an unfair and unwarranted attempt to hold the contractor for damage to the works after completion, regardless of whether or not the question is adequately covered in the specifications where it properly belongs.

Relative to Section XVIII, specifying methods of payment for extras, the writer is of the opinion that the only equitable method of payment for extra work is on the basis of actual cost, the contractor being allowed a percentage for a fixed fee as a net profit for doing the work. The unit-price method may be applied to deductions more fairly than to additions, but the writer believes that every attempt to obtain from the contractor, in advance, unit prices for additions and deductions, results in either the contractor or the owner being "stuck," unless the conditions surrounding the work be uniform.

Mr. Thurston.

Section XIX, relating to damage to persons and property, the writer believes unnecessarily verbose. The following wording would be equally effective:

"The Contractor shall indemnify and save harmless the Owner from any and all damage to persons or property caused by or incidental to, the prosecution of work under this contract, or by any act or acts of omission or commission on the part of himself or any of his employees during the life of this contract."

In Section XXIV, providing for extensions of time, the writer can see no reason for the use of the foreign phrase, "*force majeure*", in an English document, every statement of which should be as clear to all parties concerned, learned or illiterate, as the English language can make it.

Referring to Section XXXI, entitled "Liens", the writer would remark that, in view of his experience, it is possible to tie up a contractor's money to his injury by the filing of false liens, withhold notices, and the like, this section should afford him some protection, and would suggest that the final sentence be made to read as follows:

"Before the final payment shall become due, the Contractor shall deliver to the Owner satisfactory releases of all liens against the premises, including a release from himself, together with a statement of such false liens, withhold notices, and the like, as may have been filed against him in connection with this contract, accompanied by a full statement of the circumstances surrounding each, and the Owner shall proceed immediately to adopt the most direct means of paying the Contractor, without prejudice to his own interests in the building."

In Section XXXIII, providing for the termination of a contract by the contractor, there should, by all means, be included provision for payment to the contractor, on account of anticipated profits, and the writer would suggest the addition of the following phrase to the next to the last sentence:

"and in case the contract be terminated by reason of act or acts of omission or commission by the Owner, the Contractor shall be entitled to recover from the Owner, in addition to the foregoing, payment in full of anticipated profits on the uncompleted portion of the contract, points of disagreement between Contractor and Engineer to be submitted to the Arbitrators hereinafter provided for, for review, their judgment to be final and binding on both Contractor and Owner."

In Section XXXIV, relating to arbitration, the second paragraph will have to be altered to satisfy the general case, inasmuch as the provision relating to the American Institute of Architects or the American Society of Civil Engineers would be impracticable of operation outside of the vicinity of New York City.

In conclusion the writer trusts that the author will take these criticisms and suggestions in the friendly professional spirit in which

Mr. Thurston. they are offered, and will accept the writer's compliments on a very definite and well-considered attempt to accomplish a much-needed reform.

Mr. Brown. JOHN MASON BROWN, ESQ. (by letter).—The writer, having served for several years as Law Clerk to the Comptroller of the United States Treasury (in which capacity he was exclusively engaged in the consideration of cases or claims arising out of Government contracts), and having been a member of the special commission designated by President Roosevelt to standardize, as far as possible, the forms to be used in Government contracts, and having lectured on that subject before the United States Army Engineer School, at Washington Barracks, Washington, D. C., naturally takes special interest in the subject with which this paper deals. He feels confident that the above mentioned service, together with his fifteen years of practice, during which time he has endeavored to specialize on contract law, qualifies him to sympathize with the author in the task he has undertaken.

Despite the fact that the Supreme Court of the United States has frequently and uniformly held that, in its contractual relationship, the Government was vested with only the same rights and subject to only the same obligations as existed in favor of or against an individual, it requires no long memory to recall the days when a large proportion of the administrative and accounting officers and employees of the Government seemed to be determined to establish a practice and theory that there were two separate and distinct sets of law in connection with Government contracts—one applicable to the Government alone, and the other (always the more drastic of the two) applicable to the contractor alone. As a matter of fact, a few of that kind can still be found; but fairness demands the admission that they are fast vanishing; that a new order of things exists and is growing; that there is now manifested by the whole contracting machinery of the Government a sincere and *bona fide* effort and determination to do away with the one-sided contracts of former days, to draft specifications and agreements which are equitable, just, and fair in their provisions, and thereafter to administer the same so that only the contractor whose methods are corrupt or who does not properly regard his contractual obligations need fear.

Before passing to a discussion of Article II of the "Form of Agreement," attention is called to the following quotation from the paper:

"Liquidated damages should be a matter for special consideration in each separate contract. Many Engineers and Owners seem to desire them, possibly for the moral effect on Contractors."

If the first sentence, *supra,* is susceptible at all of criticism, it is so solely because the warning and suggestion are not made with sufficient emphasis. At this point, however, the writer would confine him-

self to the statement of fact contained in the last sentence of the quotation. Mr. Brown.

From personal knowledge and experience, he feels well justified in stating that it is by no means an infrequent error, on the part of owners, architects, and engineers, to suppose that they are dealing with contractors who are ignorant of legal technicalities or who do not enjoy the fullest benefit and protection of skilled legal counsel. In the first place, the fact should be clearly recognized that the personnel of "contractors" is very different to-day from what it was twenty years ago. The high-class contractor of to-day is, in the majority of instances, a college-bred man of equal training, skill, ability, and experience with the engineer or architect who represents the contractee. The "practical man" of the past has given way, in a large degree, to the educated specialist, and the latter well knows the truth of the old adage to the effect that "he who acts as his own lawyer has a fool for a client."

Accordingly, it may well be supposed that the reputable, competent, and reliable contractor of to-day does not bid for work nor sign a contract therefor without first seeking competent legal guidance. On the contrary, in most cases, before a bid is submitted, the specifications have been very thoroughly examined and digested, defects therein have been noted for possible future use, and in the submission of his bid or in the execution of his contract, the contractor proceeds with full knowledge in advance, not only as to his own obligations, but of the weaknesses and defects which exist against his contractee as well. If, therefore, according to the suggestion contained in the quotation, *supra,* a clause is inserted which attempts or seeks liquidation of damages, it is certain that the intelligent contractor has taken counsel as to its validity and enforcibility. Furthermore, personal experience doubtless has proved that the mere insertion of an attempted stipulation for liquidated damages results in an increased price or bid from the contractor. This increased price or bid may well be regarded as an insurance or indemnity against possible deduction for delay through unforeseen causes.

Let it be assumed that there is delay, and that deduction is made in final settlement. The contractor and his attorneys promptly invoke legal technicalities, and defeat the attempted provision for liquidated damages. The court holds the clause defective and unenforcible as "liquidated damages," and, under such circumstances, decrees the owner entitled to only such actual damages as can be conclusively proven to be the direct and immediate result of the breach. The result is that the contractor has received an increased price on account of the inserted clause; has made a double profit by reason of its defeat; and the owner is not fully recouped for the injury sustained by reason of the fact that he may have relied on the validity of the clause

Mr. Brown.

and, therefore, failed to keep an accurate account or proper evidence of outlay or other damage sustained by him.

Having seen and known of many such cases, the writer would unhesitatingly say that he knows of no course or procedure which he would more strongly deprecate or advise against than the insertion of attempted liquidated damage clauses "for moral effect," or *in terrorem*, or "as a bluff" to contractors. For, in the slang parlance of to-day, the bluff is sure to be promptly called; it is seldom made good; and the owner or contractee, in most cases, has to "pay the piper."

The suggested form of Article II of the "Form of Agreement" is as follows:

"The Contractor agrees that the time for completion of the works shall be considered as of the essence of the contract, and he agrees that for liquidated damages he will pay the Owner for the cost of all extra inspection, and for all amounts paid for rents, or for more protracted services on the part of the Engineer, or Clerk of the Works, or both, and other expenses entailed by the Owner by delay in completing the contract, and the Owner shall be entitled to retain from the amount otherwise to become due to the Contractor an amount sufficient to reimburse properly the Owner for such expenses. Provided, however, that the sum collected as aforesaid for liquidated damages shall not exceed the sum of $..... for each and every day's delay not caused by the Owner, or otherwise as provided in the said Conditions, Section XXIV (subject to Arbitration)."

The said article, in other words, seeks to make specific stipulation:

(*1*).—That time is of the essence of the contract,

(*2*).—That the damages for breach or delay shall be liquidated,

(*3*).—That, by agreement between the parties, they are, in fact, liquidated,

(*4*).—That the damages, as so liquidated, shall include and consist of the following items or elements:

- (*a*).—The cost of additional inspection during the delay period,
- (*b*).—The amount expended for rents,
- (*c*).—The salary of the engineer or clerk during the delay period,
- (*d*).—Other expenses "entailed by the Owner," by delay in completing the contract.

(*5*).—That the aggregate of such items shall be deducted from moneys otherwise due to the contractor,

(*6*).—That, however, the total of the foregoing "liquidated damages" shall not exceed $..... per day.

Of Items 1, 2, and 3, *supra*, but little need be said; for it is now well settled that one of the most cogent reasons and justifications for liquidated damages is the recognition and agreement in advance by the

contracting parties that time is an important, if not a controlling factor, and, therefore, made of the essence of the contract. Mr. Brown.

Proceeding to the other items, however, it is the writer's opinion that consideration of them will clearly demonstrate the fact that Article II as written is not, in effect or legal contemplation, a good, valid, or enforcible stipulation for "liquidated damages," but that, on the contrary, it is defective as such.

Article II, as quoted, affords a good example of what has already been said concerning the attempted insertion of such provisions and of the increased price or bid which they usually result in or provoke.

The following is a definition of "liquidated damages":

"The damages agreed upon in advance by the parties to a contract as and for compensation and in lieu of the actual damages arising from a breach of the contract."

Regardless of the words "in lieu of the actual damages," it is found that Article II, as suggested in the paper, provides that the proposed "liquidation of damages" shall consist of and include the following items or elements:

"(*a*).—The cost of additional inspection during the delay period,

"(*b*).—The amount expended for rents,

"(*c*).—The salary of the engineer or clerk during the delay period."

In other words, with the above definition well in mind, it will be found that the suggested Article II seeks to provide for "liquidated damages," and yet, in the same breath, proceeds, with detailed precision, to designate each and all the items of actual loss which shall be regarded as the elements of the proposed liquidation.

Article II, as suggested, designates no item as an element of damage which is not susceptible of definite and exact ascertainment, both as to amount and extent; and the question, therefore, may well be asked why an effort or attempt should thus or ever be made to provide for liquidated damages when, from the very phraseology of Article II, it is manifestly an indisputable fact that there exists or can exist neither doubt nor difficulty in ascertaining and determining the exact extent and amount of the actual damages which will result from breach or delay.

On its face, such a provision, as the writer conceives it, is inconsistent with the theory on which liquidated damages are sanctioned at all, and the reasoning which has led to their justification. They are intended to be "in lieu of the actual damages which may flow from a breach of contract." If one delves into the philosophy of the law and into the history of the development of the law, in so far as it relates to this particular topic (as distinguished from mere case law), the writer feels confident that the author will agree that the very *raison d'être* of "liquidated damages" is represented by two essentials, namely,

Mr. Brown.

(1), that time is, in reality, an essential feature; (2) that the damages which will be sustained by the contractee as a result of breach or delay, by the contractor, are essentially of such nature, character, and kind, as to render them not susceptible of definite ascertainment and determination.

Since, therefore, the items of damage provided for in Article II are so easily susceptible of exact ascertainment, why attempt to liquidate the damages? Why seek to do that which is already done by the common law?

The American courts uniformly recognize and follow the doctrine laid down in the leading English case of Hadley *versus* Baxendale, 9 Exc., page 431, wherein it was held that breach of contract by one party clearly entitles the other party "to those damages which may be fairly and reasonably considered as naturally arising from the breach."

Applying the foregoing principle to a case involving a contract for the erection of a building, the conclusion is inevitable that the law—the common law—makes the defaulting or tardy contractor liable for such actual damages as flow directly from his breach.

There are a vast number of cases wherein the courts have held that these common law damages include the actual loss, damage, or expense, to which the owner or contractee is put, by reason of the breach or delay; but if one should attempt to particularize, suffice it to say that these cases hold that:

(*1*).—The cost of inspection during the delay period,
(*2*).—The salary of the engineer during the delay period,
(*3*).—Any additional cost or expense made necessary by the breach,
(*4*).—The value of lost rentals during the period of delay, are, each and all, the proper elements of damage for which a defaulting contractor is liable.

The writer would strongly impress upon all the very important fact that to secure any such redress or rights to the owner, in case of breach or default on the part of the contractor, it is not necessary to make express provision or stipulation therefor in the contract. The common law has already imposed that liability on the contractor; the courts have uniformly upheld it; and it is indeed unnecessary to stipulate in the body of a contract that a defaulting contractor shall be subject to the law and the obligations which it imposes.

In the body of Clause 2 (referred to in the foregoing tabulation as *4-d*) is provided that, as an element of damage to be charged against the contractor in case of breach, shall be the following:

"Other expenses 'entailed by the Owner,' by delay in completing the contract."

The writer assumes that the foregoing language does not correctly represent the intention, inasmuch as a literal application of the words

used has the effect of making a defaulting contractor bear the burden of "other expenses entailed by the owner by delay in completing the contract." Possibly it was the intention to use such a word as "sustained" or "incurred" in lieu of the word "entailed," but if the word "entailed" be allowed to remain, to follow it by the word "upon" instead of "by." Mr. Brown.

The foregoing, however, in small degree affects what the writer has already stated, if it be assumed that this last clause provides for the deduction of other expenses "sustained by the owner" by reason of the delay on the part of the contractor in completing the contract. This is merely an element of actual damage, and, by the use of proper accounting methods, should be easily susceptible of definite ascertainment as to amount and extent.

The proviso contained in the last sentence of Article II is a very interesting one, inasmuch as it provides that the aggregate of the above-mentioned items of damage, designated as "liquidated damages," shall not exceed the sum of $..... for each and every day of delay. If no attempt were made by Clause 2 to provide for "liquidated damages," but, on the contrary, a mere stipulation for the deduction of the aggregate of several definite, specific items of damages or expenses, each and all of them being readily susceptible of exact ascertainment, then and in that event, one would be inclined to believe that the stipulation contained in the proviso of Article II might be regarded as neither "liquidated damages" nor as a "penalty," but rather as a stipulation fixing the maximum liability of the defaulting contractor by reason of such items. Even such a construction of this clause would be difficult to reach. For the contract provides for the deduction of the actual amounts of such items, and, in the same breath, seeks to limit the amount of the actual total.

The use of the words "liquidated damages" in Clause 2, however, precludes the idea of the construction just suggested; and, by reason of the use of the term "liquidated damages," a consideration of the whole of Article II involves the question whether it will be regarded and enforced as a provision for "liquidated damages" or whether it will be construed as providing for a penalty, and the measure of damage in either event.

In the leading case of Sun Printing and Publishing Association *vs.* Moore, 183, U. S., 642, *et seq.*, the Supreme Court of the United States, in a most scholarly and exhaustive opinion on the subject of liquidated damages, used, in part, the following language:

"The decisions of this court on the doctrine of liquidated damages and penalty lend no support to the contention that parties may not *bona fide*, in a case where the damages are of an uncertain nature, estimate and agree upon the measure of damages which may be sustained from the breach of an agreement. On the contrary, this court

Mr. Brown.

has consistently maintained the principle that the intention of the parties is to be arrived at by the proper construction of the agreement made between them, and that whether a particular stipulation to pay a sum of money is to be treated as a penalty, or as an agreed ascertainment of damages, is to be determined by the contract, fairly construed, it being the duty of the court always, where the damages are uncertain and have been liquidated by an agreement, to enforce the contract."

The foregoing quotation, from the highest National tribunal, clearly reflects the attitude, on the same subject, of many of the State courts of last resort, to the effect that the courts are not disposed to uphold an attempted provision for "liquidated damages," merely because the term "liquidated damages" appears on the face of the contract; that the uncertainty of the damages which may result from the breach is a vital element and a proper reason for a provision for liquidated damages; and that where the actual damages are not susceptible of definite ascertainment, but have been *bona fide* liquidated by an agreement, the sum stipulated as liquidated damages being on the face of the contract in a reasonable amount and not manifestly disproportionate and excessive, such a stipulation will be upheld.

In the clause suggested, however, each and all of the items are susceptible of definite ascertainment and determination as to amount and extent; the sum stipulated as "liquidated damages" is in lieu of such ascertainable amount; and it is, therefore, the writer's opinion, by reason of the foregoing, that, if the clause suggested were subject to the scrutiny of the courts, it would be held to be a defective and imperfect attempt to liquidate the damages, would be disregarded as a liquidation of damages, and, by consequence, would be construed as providing for penalty.

If the contract be thus construed as containing a defective attempt to liquidate damages and, therefore, as providing for a penalty, the stipulation contained in the clause for the payment of a certain sum in case of breach or default, is not controlling and does not limit to that sum the liability of the defaulting contractor. On the contrary, if the contract be construed as providing for a penalty, if a breach on the part of the contractor has occurred, the contractor becomes liable for the actual damages which may have been caused by his breach, without regard to the sum named, and without regard to any excess over the stipulated amount.*

Attention is called to Section XXIII of the "Schedule of Conditions of Contract."

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*Foley *vs.* McKeegan, 66 Amer. Dec., 107; Lord *vs.* Gaddis, 9 Iowa, 267; Shreve *vs.* Brereton, 51 Pa. St. Rep., 175; Hale on Damages, 127; Graham *vs.* Bickhan, 4 Dallas (U. S.), 143; Amer. & Eng. Encyc. Law, Vol. 13, pp. 867-868; Noyes *vs.* Phillips, 60 N. Y., 408.

Reference should also be made to "Architectural and Engineering Jurisprudence," by John C. Wait, in Sections 315, 316, 317, 318, 319, 320, and 322, of which will be found a very complete compilation of citations from the various courts of last resort.

Mr. Brown.

The second paragraph reads as follows:

"Should the Contractor, by his own fault or negligence, unnecessarily delay the completion of the work, thereby necessitating unusual or more protracted services on the part of the Engineer or the Clerk of the Works, or both, the Owner shall be entitled to retain from the amount otherwise to become due the Contractor an amount sufficient to reimburse properly either the Engineer or the Clerk of the Works, or both, for such protracted or unusual services (subject to Arbitration)."

Of this Section the author states:

"This section should be read in connection with any damages to be allowed under Article II of the Agreement. It should be distinctly stated in the Agreement whether or not the specified sum for damages includes the protracted services of the Engineer, etc., herein mentioned. In many cases, compensation for such protracted services might be all the damage that should justly be demanded."

If, in their general conditions, the specifications forming a part of the contract contain such a provision as that just quoted from Section XXIII, it would indeed afford the strongest evidence and the best possible basis for argument that the stipulation in Article II of the suggested "Form of Agreement" provides for a penalty and not for "liquidated damages." It is true that where the specifications and the formal contract conflict, the provisions of the latter instrument prevail and control; but it is equally true that in cases of seeming conflict and ambiguity, it is a common practice to read the two together, in order that the apparent intention of the contracting parties may be sought and found.

With the author's dictum in connection with the proposed Section XXIII, the writer is unable to agree. It is neither essential nor desirable that the agreement should state, either in the body of the contract or in the general conditions of the specifications, that "the specified sum for damages includes the protracted services of the Engineer, etc." For, if the contract be held to provide validly for liquidated damages, it is indeed unnecessary to specify in detail the elements which go to make up the stipulated amount. For that sum, if the liquidation be valid, is in lieu of the actual damages, and it is in no sense influenced in such a case by the recitation of its component elements. On the other hand, if the attempted liquidation be held invalid and unenforcible, then it is likewise unnecessary to make the suggested stipulation. For, if the contract be construed as providing for a penalty, then as before stated, the breach by the contractor entitles the contractee to his actual, proven, and direct loss, damages, or additional expense, and the courts have held that the salary of the engineer or inspector during the delay period is a proper element of damage to be recovered. If, therefore, as shown, the common law in

Mr. Brown.

this latter case sanctions the recovery of this item, why seek to specify for it or to reaffirm the law from which one cannot escape?

It is earnestly hoped that the foregoing will not be construed either as a statement or as an evidence of belief on the writer's part that a valid and thoroughly enforcible stipulation for liquidated damages for each and every day of delay cannot be inserted in a building agreement. He intends to convey no such impression and to justify no such conclusion. He has not attempted to consider the whole subject in this discussion but, on the contrary, has confined himself to a consideration of the provisions contained in the paper.

Attention is called to one other point, namely, if liquidated damages are not provided for in the contract, but, if, on the other hand, it be the intention and desire of the owner or his architect to hold the defaulting contractor responsible only for the actual loss, damage, or additional expense occasioned through his default or delay, then the writer would very strongly advise against an attempted enumeration of the items of damage for which the contractor shall, in such event, be held responsible. It is difficult to provide for greater redress or better protection than the common law affords. On the other hand, it is dangerous to attempt to enumerate specific items or elements of actual damage which will be enforced; for, in such attempt, it will often be found that the contractor's attorney will invoke, and the courts sustain, the ancient doctrine of *Unius inclusio est exclusio alterius*. In other words, the courts have held very consistently that where a contracting party stipulates in detail for certain items or elements of damage, he will be presumed to have waived the common-law rule of damages and to have stipulated for the only protection and redress which he desires.

The writer sincerely hopes that what he has stated in this discussion will be accepted in the spirit in which it is meant. He realizes perfectly that it is incomplete by reason of the small amount of time which he has devoted to it. He is deeply interested in the subject, and the difference of view which he has taken is prompted only by the most friendly spirit and his earnest desire to see many mistakes of the past corrected and a more harmonious relationship promoted between parties to building and engineering agreements. Much of what he has said is inapplicable to contracts for essentially engineering propositions; but as the writer understands that the paper relates purely to building agreements, he has confined his remarks to contracts of that class.

Mr. Waddell.

J. A. L. WADDELL, M. AM. SOC. C. E. (by letter).—This paper marks an important advance in the writing of engineering contracts. In discussing it little can be said except to approve, for there are few points to criticize and none to condemn.

Mr. Waddell.

The general feature of absolute fairness to the contractor, which is characteristic of the paper, is highly commendable. Too many employers try to treat their engineers merely as hired men who are paid to do simply as they are told, and to work solely in the interests of their principals, whether the latter be in the right or in the wrong. No self-respecting engineer will lend himself to such a degradation of his profession and to such a stultification of his ideas of equity and justice. The writer remembers being called severely to task by one of his principals for being, in the opinion of the same, too liberal to a contractor. Waxing wroth, the principal remarked, "What do I pay you for, anyway?" to which the writer replied, "Whatever it may be, it certainly is not for skinning your contractors." The status of the engineer in his dealings between principal and contractor ought to be distinctly and authoritatively defined by the Engineering Profession as a whole, as being that of a judge and never that of a partisan.

Mr. Bamford enumerates six methods of contracting for work, but he omits one, which, in the writer's opinion, is far better than any of the others, *viz.*, that of unit prices for all materials in final place on the work. The writer has used this method almost exclusively for nearly a quarter of a century, and has invariably found it to be satisfactory to all parties concerned, because the contractors are paid for exactly what materials they furnish and for what work they perform—no more and no less.

The main objection to the lump-sum basis is that the contractor is constantly tempted to cut down the quantities of materials entering into the work, and, in consequence, there is continual friction between him and the engineer, the result generally being that, in spite of the vigilance of the latter, less materials are used than are called for by the plans. This is eminently true in the manufacture of bridge superstructures. If the engineer's plans and specifications are thoroughly and properly prepared, any omission of materials or cheapening of work is a detriment to the construction.

It is sometimes claimed that when the contractor is paid by schedule rates, there is a tendency for him to put in more materials than are called for by the plans. This criticism of the unit-price method applies mainly to the manufacture of metal-work, in which there is a certain permissible variation of weight; but the writer notices that, as his specifications state distinctly, "if the excess allowance be over-run the extra amount will not be paid for," he never has any trouble with his contractors, because of excess in quantities.

Any method of paying for work at cost plus a percentage or cost plus a lump sum is unsatisfactory and always unnecessarily expensive for the principal, because, no matter how honest the contractor may be personally, nor how much he may desire to expedite construction or economize thereon, it is absolutely impossible under such conditions

Mr. Waddell.

to force his employees to do the full amount of work which they would perform if they knew that the effectiveness of their labor would result in his personal benefit and not in that of the company. The old adage that "the company's rich" is both quoted and acted on by the laborers, when their employer is paid on the basis of actual cost plus a bonus; and nothing can prevent the continuance of its injurious influence under such a condition. The writer knows whereof he speaks, for he was once compelled by unusual conditions to let some $2 000 000 worth of construction at cost plus a percentage, and although the contractors themselves were faithful and honorable, their employees could not be forced to do an honest day's work. In the writer's opinion, the cost-plus-a-bonus method of letting work should be treated as a last resort.

Contracts and specifications should be drawn as full and complete in detail as they can be made. Any omission or ambiguity in them will result in loss to one of the two parties to the contract—and sometimes to both. Usually, though, the loss falls on the principal, if the matter gets into the courts, for the reason that the under dog generally gets the most sympathy. The writer has always endeavored to make his contracts and specifications full and complete; and the more his experience has increased, the more elaborate have they become, until now each contract and specification is almost a treatise. He has been adversely criticized at times for this, but sees no good reason for changing his practice. Several years ago, in calling for bids on some foreign bridge work, he took special pains to investigate the conditions affecting the erection and to describe them in detail in the specifications. For so doing he was called to task by the chief engineer of the railroad, who said, "Let each bidder go over the ground and find out such things for himself. If he makes a mistake, he will have to stand the loss involved; but, if any of your statements are wrong, the company will be held responsible for them." Such a policy, besides being dishonest, is short-sighted; for if a contractor makes a mistake in his estimates and obtains a contract for less than the cost of the work, he will either throw up the job or find some means of cheapening the construction so as to complete the work without loss to himself. Again, when the information given in the specifications is meager, in order to protect themselves the bidders will tender high, and thus the illegitimate object of the writer thereof will be defeated. Personal experience has proved to the writer that the more complete and thorough the information given in the specifications about any proposed work, the lower will be the tenders received.

The English method of "Quantity Surveying," mentioned by the author, is cumbersome and not adapted to hurried work; for not only must all plans be finished in detail before bids are called for, but also complete and accurate bills of all materials must be given in the specifications.

Mr. Waddell.

In calling for tenders by unit prices, the writer makes a practice of giving, in his specifications, an approximate list of quantities of all the materials which will probably enter into the construction, and this list is used in comparing the different bids submitted; but it is always distinctly stated that the company shall not be held responsible in any way for the correctness of these approximate figures. The estimate for such quantities is easily and quickly made, and it serves its purpose quite as well as a much more exact one.

The author's clause concerning liquidated damages is notably just and equitable, but its application would generally involve great difficulty in determining just what total expense the owner has been put to because of the contractor's delay. The writer thinks that his own method of stating in the specifications an amount of liquidated damages for each day of delay, and of not enforcing the said damages without good and sufficient reason, while theoretically not quite as perfect as the author's method, is practically much less difficult to apply.

The writer endorses the author's method of dealing with the question of retained percentage. It is quite an improvement on the one now in vogue in America.

The writer is pleased to note that Mr. Bamford insists that all plans are the property of the engineer who made them, and that the contractor, on the completion of the contract, must return to him all copies thereof. The right of an engineer to retain possession of his designs, after they have been utilized by his principals or others who have paid for their use, is not generally acknowledged by the public; but it is hoped that the time is not far distant when American engineers will be protected effectively from the theft of the product of their brains.

In regard to extras on construction, in the writer's practice, which involves payments by schedule rates, any extras which may arise, pertain to labor and materials which were not contemplated when the specifications were drawn; and he always endeavors to arrange, in advance of the construction involving these extras, a special schedule price (or, in certain cases, a lump sum) to cover them, notwithstanding the fact that his latest specifications provide that such extras are to be paid for at the actual cost of the materials and labor involved, plus 20% for profit, no allowance being made for use of plant, administration, insurance, interest, or any other item, except the said materials and labor. This arrangement is quite as advantageous for the owner as the ordinary one of paying 10% of the cost for profit, and permitting the contractor to introduce all kinds of expenses to swell the amount of his bill.

For many years the writer has had, in his personal contracts with his principals, a clause by which the owner shall withhold from the contractor's final compensation, even if the liquidated damages clause of

Mr. Waddell.

the contract between owner and contractor is waived, a sufficient amount to compensate the engineer for all losses due to the contractor's failure to complete his entire work in the contract time. This policy was adopted after several unfortunate experiences. The writer is glad to see that Mr. Bamford provides for such an arrangement in his form of contract.

The author's clause in relation to "Extension of Time" is excellent. It outlines the course which every just engineer should adopt in case of delays.

His provision for the termination of a contract by the contractor for good and sufficient reason is an advance along the lines of equity and justice, and it ought to commend itself for adoption by all right-minded engineers.

The settlement of all disputed points by arbitration is theoretically an ideal means, in that it should save much time and money; but, unfortunately, in America either party has a right to appeal to the courts against the decision of the arbitrators, thus rendering all their work null and void; hence, it is advisable that, before referring the evidence to the arbitrators, each party should give a bond involving a large forfeit to the other party in case he fails to accept the award of the arbitrators.

Mr. Bamford's idea of damages for submission to arbitration, or, in other words, compensation by the party found to be in the wrong to the other party, for the latter's expenses connected with the arbitration, his loss of time, etc., is a step in the right direction, which the writer would like to see established as a precedent, not only in arbitrations, but also in courts of law. It has always appeared to him to be rank injustice that a rich scoundrel should be allowed to force a much poorer man to go to law in order to obtain his rights, and after he has finally won them from the court of last appeal, to be compelled to pay all that he has won (and sometimes even more) to his lawyers, his witnesses, the court clerks, stenographers, and other claimants. It would be far better for the court to make the losing party pay all such expenses.

There is no mention in Mr. Bamford's "Schedule of Conditions of Contract," nor in the "Agreement" itself, of a bond guaranteeing the completion of the work according to the terms of the contract and specifications. This is an important feature, and it should never be ignored, unless the contractor be of such high business standing that a guarantee is unnecessary. For instance, it is not customary to ask large bridge manufacturing companies to give bond for the manufacture of bridge superstructures, although it might be advisable to insist on a guarantee in case they undertake the erection also.

The writer* gives the following clause in relation to bond:

* "Specifications and Contracts," p. 79.

Mr. Waddell.

"The Contractor further agrees to give to the Company a surety-company bond, satisfactory to the party of the first part in the sum of ..... for the faithful performance of this contract and the specifications, and of all the terms and conditions therein contained, and for the prompt payment for all materials and labor used in the manufacture and construction of the structures, and to protect and save harmless the Company from claims on patents and from all damages to persons or property, caused by the negligence or claim of negligence of the Contractor, his agents, servants, or employees in doing the work, or in connection therewith, and from injury to or loss of materials paid for by the Company either partially or in full before the completion and acceptance of the construction or constructions."

Incidentally, it might be mentioned that, as far as the writer's experience is concerned, a surety-company bond is the only kind which is in every way satisfactory. The obtaining of it by the contractor is simply a matter of business, and is in no sense a favor, as most personal bonds usually are.

The proper dividing line between any contract and its accompanying specifications is still a moot point among engineers. The writer's practice is to put everything possible into the specifications and thus reduce the length of the contract proper to a minimum, but it is evident from the paper that the author does not agree with him on this question.

Mr. Bamford is to be congratulated on having prepared and presented to the Society such a thorough and complete paper on a subject which is of the greatest importance to the entire Engineering Profession. It is worthy, not only of perusal, but also of discussion by the most active and prominent members of the Society, especially by those who are engaged in consulting practice.

Mr. Moore.

De Witt V. Moore, Esq. (by letter).—The suggestions submitted by Mr. Bamford are opportune and of the most vital importance to all who are interested in building construction. In the main, the writer is in harmony with these suggestions and only desires to mention a few points where possibly his personal experience may be of benefit. The time has come when the present forms of agreements and specifications should be thoroughly revised and all obsolete and unfair clauses and stipulations eliminated.

In no line of construction work has there been more progress than in the intellectual, educational, and technical improvement of the personnel of those engaged in the vocation of contracting. As a Member of the American Society of Engineering Contractors, the writer asks that the engineering contractor's advice be requested on this subject, to the end that all may profit by his practical experiences and, further, that all may work in a closer relationship of mutual respect.

No attempt will be made here to discuss the wording of the paper,

Mr. Moore.

as the writer feels that this is a subject for very careful consideration by a special committee, preferably a joint committee from all the interested organizations.

The writer cannot quite agree with Mr. Bamford's division of the systems of contracting into two general classes. He believes so thoroughly in the "cost plus a fixed sum with a guarantee of the cost, or with a bonus and penalty clause" form of contract, that he thinks this method is deserving of a classification of its own, or, in other words, he would divide the systems into three classes. It, therefore, follows that he believes the "cost plus a fixed sum" form of contract to be preferable to any other.

He also cannot agree that the lump-sum contract is the more economical. In his judgment, the cost plus a fixed sum contract with a bonus and penalty clause occupies this position for the following reasons:

*First.*—While the engineer may be of unquestionable ability and the plans and specifications may be excellent, still as an engineer, his specialty is the designing of structures for an intended use. This is a day of specialties, and the engineering contractor engaged entirely in construction is more familiar with materials, methods, and costs, and he can often suggest changes which will in no way affect the quality or ultimate value of the work, but which are more economical. With a bonus clause contract, he has every incentive to study the plans and specifications in order to accomplish such savings and, in so doing, is working to the best advantage of all parties concerned.

*Second.*—The engineer will give far more consideration to the suggestions of a contractor with reference to proposed changes and substitutions under a "cost plus a fixed sum, bonus and penalty contract," than he will under a lump-sum contract, for, in the first case, the interests of the engineer and the contractor are mutual, *viz.*, to secure the best results at the least cost; while in the second place, the engineer is suspicious of the contractor's motives.

There can be no question that the usual form of percentage contract is not to be desired except under special and abnormal conditions, where either the cost is not obtainable by estimate or where the amount of work to be done is not determinate. There is, however, one very important feature to be brought out in either a "cost plus a fixed sum" or a "cost plus a percentage contract," and that is the addition to the contract of a schedule which defines absolutely just what items are to be considered as a part of the cost. This is so important that a paper could be written on this subject alone.

The English method of "Quantity Surveying" is theoretically desirable, but is not practical. The idea of a professional Quantity Surveyor estimating all the quantities entering into a piece of work, itemizing the same, and submitting them to all the contractors calculating the

cost, is beautiful in theory, but by this method two of the most important elements affecting estimating and contracting are entirely overlooked: Mr. Moore.

*First.*—It is not to be expected that any two Quantity Surveyors, unless in the same office, will estimate or itemize in exactly the same manner, and there is always an uncertainty in the contractor's mind as to just what is intended or included.

*Second.*—No two contractors will take off work in exactly the same manner, or group work in the same way, because of the individuality of the concern and the individuality of its method of cost keeping. Therefore, the quantities taken off by a Quantity Surveyor may not be in such a form as to secure the best thought of the contractor.

Such a method is likely to result in the Quantity Surveyor and the contractor working in the same rut.

To a great extent, the cost and results obtained in any piece of building construction depend on the specification writing more than on the plans. As a contractor, the writer desires to state that it is astonishing how many times bids are made on work on which the owner could have saved considerable money and secured better work if he had allowed the contractor specialists to write their own specifications and had discarded those proposed by his architect or engineer. Outside the subject of contract forms, there is work for a joint committee for an extended period of time to reduce to standards all specifications for standard lines of work and then to insist that such standard specifications be used in connection with the accepted standard form of contract. Efforts have been made along this line, but because they have been confined very largely to manufacturers and specialists, the general public is suspicious and will be until such standard forms are endorsed by the leading architectural and engineering organizations.

Human nature is very much the same no matter what the profession or vocation. The placing of an engineer as the final arbitrator of all controversies between the owner and contractor is not a fair requirement. As an arbitrator, the engineer, if unfair, has the advantage of all the unfair clauses in the contract. He may also be influenced by an unfair owner, but, above all, human nature will prompt the engineer to consider his client first and the contractor second. As his recommendations are based on the owner's satisfaction, the fact as to whether the contractor is pleased is of very little consideration. The contractor is dependent on the engineer for work and not *vice versa*.

It is certainly true that it is important in the conception of any proposition to anticipate the conditions and circumstances which may result in changes in the plans and specifications, but the stipulations in the contract and general clauses of the specifications may be ar-

Mr. Moore.

ranged so that all such changes may be easily adjusted, and in this connection the writer desires to compliment Mr. Bamford on his broad-minded suggestions.

It has often been a question with the writer whether the ordinary owner and his architect realize that excessive retained percentages are considered by the contractor as a part of the cost of the work and that in the end the owner pays the bill. Such methods do not work to economical costs and serve no purpose whatever where the owner is giving his work to a reliable firm of contractors. If the contractor is selected for his general ability and standing, the reserve percentage may be kept very low, to the mutual advantage of all parties concerned.

Section I of the "Schedule of Conditions of Contract" is pleasing. It is just such fair-minded wording of general conditions that will result in the most economical cost of work. The contractor is often a better judge as to what changes, in the nature of extras, are necessary than the engineer, and in the drawing up of standard contracts or specifications, consideration should be given to the fact that the contractor is in reality a cost engineer, and his opinion should be sought.

The writer agrees with the author as to Section V. The contractor should not be called on to guarantee property lines or grades, but he should be capable of maintaining both, after they have once been established by the owner.

The sub-contractors mentioned in Section VII should receive even more consideration that is given them by Mr. Bamford. While it is true that they may not be recognized legally as parties to the contract, still in the payment to them for work done they should be protected to the extent of the actual cash due them. While the subject of fairness in contracts and specifications is being considered, the sub-contractors who, in the aggregate, suffer more than the general contractor, should not be forgotten. After the engineer has approved a sub-contractor, he should be thoroughly cognizant of the nature of his contract and the amount he is to receive for his work, and then protect him from the avariciousness of the general contractor; and, in case of the completion of the work, he should not accept from the general contractor a bond guaranteeing the payment of such bills. The writer has known of cases whereby such a method has resulted in the general contractor securing all the actual cash due and afterward going into the hands of a receiver; the sub-contractor suffered the loss.

Section X should be worded so that no workman, otherwise good, should be dismissed from the works because of possible personal dislike or antipathy by the engineer in charge.

The fair wording of Section XII should appeal to the owner, the engineer, and the contractor.

The subject of extras, as mentioned in Section XVIII, is without

Mr. Moore.

doubt the cause of more trouble, hard feelings, and enmity than any other feature of contracting work. Nearly every specification or contract will provide for written instructions, but experience has taught us that engineers are not quite so ready to follow their own specifications in this matter as might be expected. It is very common to receive instructions to proceed entirely on a basis of verbal requests, and the result is a feeling that the contractor is taking advantage of the situation when he delivers his bill for extras. Unless the work is very certain of estimate, or is extensive, the best method of payment is by "cost plus a percentage," as mentioned in Method *C* of this Section. By using this method, the contractor has the opportunity of submitting records and detailed information as to costs in order to substantiate his bill.

In the the matter of extension of time, as mentioned in Section XXIV, there is no doubt but that the ordinary specification and contract is not adequate. The wording suggested is good, but the subject is so important that it should be given a great deal of thought before being made a part of any standard form.

Section XXXI covers, in a very complete manner, the subject of liens. The question arises here whether it is safe and wise to allow the release of a lien by the giving of a bond. There is danger of litigation in such a method.

Section XXXIII, allowing for the termination of the contract by the contractor, covers a long-felt need. Most contracts, regardless of the character of the work, are so one-sided, in favor of the owner, that the effect to the contractor is to place his head in a noose whereby he may be hung, his only hope resting, not alone in the fair-mindedness of the owner and engineer, but in their magnanimity. Such a condition is not wise, from a business standpoint, nor can the best results be secured without equal justice to both parties.

The contractor should not be called on to guarantee plans or specifications, nor to report and rectify errors of omission in the engineer's plans. He is engaged for the purpose of constructing the work after it has been designed. If an engineer has any doubt in his own mind as to the value of his plans and specifications, he should advise the employment of a consulting engineer rather than ask a possibly ignorant party to guarantee the construction. After all, the question is how much such a guarantee is worth to the owner.

In conclusion, the writer desires to make an earnest appeal for a combined effort by architects, engineers, and contractors, to eliminate all these objectionable features in the present forms of contracts and specifications, and to prepare new matter so that it will adequately cover and describe the work to be done, and yet carry justice and equity to both parties to the contract.

Mr. Allen. LESLIE H. ALLEN, ESQ. (by letter).—As the Agreement prepared by Mr. Bamford is for lump-sum contracts only, the writer will confine his discussion chiefly to that part of the paper which deals with this form of contract. A number of facts pertinent to other forms of contract, however, will be brought out in discussing particular clauses in the Agreement.

Immediately after his designation of the various forms of contracts, Mr. Bamford says: "Of these, the lump-sum system is the most usual, and is theoretically the best."

It is true that the lump-sum contract has been most in vogue in the past and, even at the present time, most contracts are probably of this type. It is very doubtful whether this form of contract is even theoretically the best.

The result of working under this form of contract is that at the end of a job the contractor finds that he has made more than a fair, legitimate profit; or (as is more usual) that the job has cost more than he estimated, and his profit is correspondingly less.

It would seem, as Mr. Bamford states, that as far as the owner's interests are concerned, lump-sum contracts are usually the cheapest, but this does not always mean they are the most economical.

There is a growing feeling among building owners of the better class that "the laborer is worthy of his hire," and a growing desire on the part of the better class of contractors to take only those contracts which insure a fair profit. This is leading to the general adoption among private owners of the various percentage and fixed-profit contracts mentioned by Mr. Bamford.

The monetary advantage of "catching a sucker" on a lump-sum contract is usually more than offset by the trouble of making him perform his contract, vexatious claims for extras, poor work, scamping, delays, and disputes. The Aberthaw Construction Company, with which the writer is connected, in looking up work it has failed to get, finds many owners, who, having accepted low bids, have afterward expressed the wish that they had let their contract to a better contractor at a higher figure.

In most cases owners will get only what they are paying for. The writer's company does not hesitate to tell owners that they can probably get lower bids for reinforced concrete buildings by taking them in open competition than the price for which that company would be willing to build them. By making such statements the company is securing more and more of the better class of business from the best class of manufacturers. Mr. Bamford makes the following statement:

"Such a system pre-supposes that the contract [specification?] defines the work to be performed, and that a contractor, therefore, can determine accurately what the execution of such work will cost."

Mr. Allen.

It has been the writer's experience that this is never the case. However clear the drawings and specifications, and however accurately predetermined the conditions of work may be, the writer's experience during the last 16 years shows that, neither on any single item, nor on the sum total of any contract, is it possible to determine accurately what the execution of a job will cost, even in spite of a system of cost keeping and methods of estimating considerably more accurate and careful than those generally used. Any contractor who keeps an accurate record of costs will bear out the truth of this statement in his experience.

One of the greatest causes of trouble with lump-sum contracts is their inelasticity. A piece of work is very seldom started in which the owner or engineer does not desire some changes in the original plans and specifications before it is completed.

This brings up the much abused question of extras. Mr. Bamford indicates by Section XVIII that it is often necessary or at least desirable to adjust the cost of extras by some form of contract other than the lump sum. Under Method *B* of this Section is set forth a method of adjusting extras "by unit prices." The writer wishes to discuss this clause briefly, and will first quote it as it stands in Mr. Bamford's paper:

"*B.*—By Unit Prices. Where the Contractor shall have given, in his estimate for the contract, or in subsequent accepted estimates, unit prices for specified parts of the work, the Engineer may make an award of a sum based on these unit prices, subject to Arbitration."

The great difficulty (and the cause of many unbalanced bids) appears to be the fact that the engineer's units of cost are not the contractor's units. Until engineers' quantities represent, item by item, the actual operations of the proposed work, it will not be possible for competing contractors to make bids which compare closely with one another. For instance, in bidding recently on a bridge, four different classes of concrete (Class A, Abutments; Class B, Center Piers; Class C, Arches; Class D, Parapet) were given, and the contractor's price on these had to include coffer-dams, pumping, excavation in the river bed, dry excavation for abutments, forms, and surface treatment. No doubt it saves trouble for the engineer to decree that concrete only shall be measured, but the contractor is invited to gamble on whether Class A concrete (Abutments) would necessitate close sheeting in the excavation, and whether pumping would be necessary; and in Class B (Center Piers), each foot in depth below water line would increase the cost of the units enormously. On the same job, Class D (measured in linear feet) included cast-stone balusters, concrete pedestals and coping, cast-iron lamps, and glass globes.

On a similar job before the writer, Class D concrete included

Mr. Allen.

granolithic paving, iron manhole covers, and concrete parapet walls and balusters. In the case of concrete walls, say, 12 in. thick, to be paid for by the cubic yard, including forms and finish, if the engineer elects to reduce the thickness of the wall to 8 in., the contractor has to do just as much form work and finish, although he is paid for only two-thirds of the amount.

Instances of this kind could be multiplied, but these are typical of unit prices on which contractors are continually being asked to bid, and it is small wonder that the range in bids is very marked. In the writer's experience it is generally necessary to take off from fifteen to twenty items in order to make up a unit price on one of an engineer's units. It requires much more time and trouble to bid on unit prices than on a lump sum, and the results to the contractor are much less certain, because a small increase in yardage of concrete or excavation, as the case may be, may necessitate expenditure on his part which could not be foreseen or calculated; or a decrease may deprive him of remuneration for work necessary to the completion of the contract, but not itemized on the engineer's schedule.

It would seem that if the engineer would also price his units before sending them to the contractor, a further speculative element would be introduced, as it would be impossible to reconcile the unit prices of the engineer with those of the contractor, and the latter must base his plus or minus percentage bid on the assumption that the quantities will turn out exactly correct, or "take a chance" on certain items being in excess and bid accordingly. The alternative to this would be to bid a different percentage on each unit.

Even if the engineer were to prepare an accurate bill of quantities, setting out therein all the items that a contractor would price in estimating, contractors' prices vary so much, owing to differences of methods, equipment, cost keeping, and judgment in estimating, that no two would be likely to bid in like proportion on every item, and the engineer's bid would still be of no use.

The percentage system of bidding has been tried in England, where quantities are certainly prepared accurately and include a great amount of minute detail, but the system has never found favor, and is seldom used. Two public bodies, the War Office and the London School Board, have priced schedules running into hundreds of pages and thousands of items, but their use has been limited to jobs costing not more than $500, as they do not work satisfactorily.

Sections XVI and XVII are very closely related, and as the discussion of them may also apply to some extent to Section VIII, it may be well to examine these before proceeding.

Mr. Bamford evidently realizes fully the difficulties in the way of drawing up clauses to cover the above points with fairness to both owner and contractor, and he has made an extremely good attempt to

Mr. Allen.

correct the usual defects. The following is merely the relation of some of the writer's actual experiences in regard to the use of copies of quantities and the adjustment of variations, as provided for in Sections XVI and XVII. This system is generally used in England, and works well, but it is full of pitfalls for the unwary, and should be adopted with caution.

It has been the practice of the writer's company to be unusually frank and open in the matter of showing estimates to owners and engineers. Recently, in taking a contract for some large concrete mill buildings, the estimate was deposited with the architect so that he might copy it for use in adjusting any variations. In making the estimate, the company had only sketch plans of a brick-and-timber structure from which to work, and had to assume all details necessary to give the same accommodation in a concrete building with brick curtain walls and guarantee that the cost of such a structure should not exceed a certain figure. The architect gave a copy of the estimate to the owner, who discovered by measurement that the estimated quantity of brickwork was largely in excess of that actually laid, and thereupon asked for an adjustment. The reason for the discrepancy was that the company had figured on smaller windows than had been put in and more brickwork, and it was found that the amount saved in brickwork had been lost in windows, but the owner was not satisfied, as the number of windows was the same. The terms of the contract did not permit of this being considered a variation, and though the legal position of the company was clear, it preferred to give way and remain in good standing with the owner rather than fight it out.

On another job, gained in competition by a narrow margin, a copy of the estimate was deposited with the engineer. When the job was nearly finished, the owner decided to build another building close by. The engineer made plans and figured it upon the former estimated prices. It had been found that, through unforeseen circumstances and unexpected difficulty in one portion of the work, some of these prices had not been remunerative, and when the company was asked to estimate on the new plans the prices of these items were raised, consequently the bid was higher than the engineer's estimate. He offered to give the work to the writer's company at his figure, or to put it out to open competition again, when undoubtedly those who had bid before would use the same prices and bid below the company. Thus there was the alternative of practically declining a job for owners who had additional building work to be done, or taking the job at a price which would barely insure any profit.

In another instance, when showing an estimate to an architect just before signing the contract, he discovered that the price on skylights and roofing was much higher than a figure he had obtained. He promptly proposed to take this item out of the contract altogether and

Mr. Allen.

let the owner pay it direct, regardless of the fact that other items might have been figured too low, and it was with difficulty that he was turned from his purpose.

Obviously, from the writer's practice, he does not find that it is always a disadvantage to give information as to estimates. Frequently it has been found to be of very great benefit in leading toward that state of mutual confidence and respect which always should, but frequently does not, exist between owner, engineer, and contractor; and, in the adjustment of extras, he has found that it has often saved a lot of dispute, and secured a just and fair settlement, to both owner and contractor. It is not suggested that all engineers or owners would act in the ways indicated, if furnished with priced quantities, but, as Mr. Bamford's suggested agreement, if adopted, would be used by all alike, whether reasonable or unreasonable, partial or impartial, it is desirable to point out some of the difficulties encountered in following this practice.

The depositing of quantities should be an optional matter with the contractor and the engineer. It is largely a matter of judgment whether they will or will not be an advantage in any particular set of circumstances.

It is easier for an unscrupulous contractor to submit an unbalanced priced schedule than to submit an unbalanced bid, with far more advantage to himself and loss to the owner, and the writer could quote several instances, within his knowledge of English practice, which have resulted in unfair profits to the contractor, and no redress for the owner.

In reference to damages for delay (Sections II and XXIII), it is only fair that if the contractor should pay for delays caused by him, the owner should reimburse the contractor for delays caused by himself or his engineer. Such delays often cost the contractor large sums in fixed charges, plant rental, foremen's time, etc., and he has no redress whatever.

In a rush job, recently (a factory erected during the winter, with a heavy forfeiture clause for non-completion within the contract period), the engineer stopped the concreting for a week (a warm week when work would have gone fast) in order that he might test a sample of two bars of the steel reinforcement; and later, owing to a mistake he made in testing cement, he condemned three or four cars of cement (which three independent laboratories reported as first-class), and caused a lot of delay and expense. As he refused to grant any extension of time, the company had to spend a lot of money for night work.

In regard to arbitration, the English system generally works well, and if procedure in the United States were standardized on similar lines it would prove beneficial. In general, the submission after the completion of the work is fair to all, but it will be realized that cases

arise when leaving big disputes undecided may work real injustice to one of the parties. The arbitrators should decide whether the dispute is to be adjudicated upon during the process of the work, during a cessation of the work, or at its close. Mr. Allen.

Mr. Bamford's effort to produce a contract which recognizes the rights of both sides is a step in the right direction, and the thanks of contractors are due to him for the thoughtful care with which he has dealt with the subject. It is to be remembered that it is impossible to foresee and provide for every contingency which will arise between the parties to any contract, and the aim of a contract should be to secure equitable dealing between the parties and a mutually fair interpretation of what was in their minds at the time the contract was made.

WILLIAM B. BAMFORD, ASSOC. M. AM. SOC. C. E. (by letter).—The writer has been gratified by the interest which has been shown in this paper by those who have discussed it, and also by the many personal letters received from others and expressing interest in the subject. Mr Bamford.

Two general methods to ensure justice and fairness between the parties to a contract seem to be advocated: The first is to ignore the specific wording of the contract and rely on the engineer, in his judicial capacity as interpreter of the contract requirements, to construe them from the standpoint of a judge in equity rather than from the more severe position of a judge interpreting the law. The second method is to try and prepare contracts which shall be just and fair to all parties, and give to the engineer proper power and authority to see that both parties receive their share of justice under the contract provisions.

The feelings of those who lean toward the first of these measures for relief could not be better expressed than in the following extract from an address by Onward Bates, Past-President, Am. Soc. C. E., before the graduating class of 1909 of Rensselaer Polytechnic Institute:

"One of the most frequent examples of the weakness of engineers in dealing with men is found in their relations with contractors. It is common for engineering work to be done by contract, under the supervision of engineers, and the control of the work and settlement of accounts is a fruitful source of trouble to the engineer. In the first place, engineering contracts are nearly always wholly one-sided, being drawn by the engineer or his employers, and reserving all rights and privileges that are possible for their side, while giving the contractors as few as possible. It is proper enough that the engineer should be the one to decide points of dispute with the contractor, and this places with him an extra responsibility, making him both an interested party and a judge of questions in dispute. It takes a high-grade man to meet such a situation with justice and to secure the harmonious co-operation of the contractor which is necessary to good results for both parties. It is here where it becomes evident that the engineer should be a judge of human nature, knowing how to deal with men, and that he should

Mr. Bamford.

be endowed with common sense, tact and justice, and with a conciliatory spirit. There is much unnecessary friction between engineers and contractors, and I think this oftener happens with young engineers than with older ones. Young engineers are apt to lay too much stress on the contract clauses, giving them practically unlimited power over the contractor, and to become arbitrary in dealing with him. The safe rule is to look at both sides of the question and then do what is right. As his judgment matures with age, he becomes more considerate. It is a good thing for an engineer to have some experience as a contractor, or in the service of one, for it gives him a better grasp of the rights of both sides in a controversy. It is also well to study the work from a contractor's standpoint, to get correct ideas of cost, and to learn how to handle men. * * * The old idea that engineers are saints and contractors sinners is going out of fashion. The men are the same under either title, and engineers become contractors without loss of self-respect, and without losing their rank as engineers."

There are many difficulties and dangers confronting an engineer who follows the dictates of his conscience rather than the contract requirements, especially on government or public work.

It must be unhesitatingly conceded that the success or failure of any work depends largely on the personality of those connected with it, but, as the written documents are the legal instruments which define the duties, obligations, and responsibility of the engineer, as well as those of the owner and contractor, it would seem most important that engineers prepare their contract documents with extreme care, and not trust entirely to their judicial position to right any unfair requirements discovered in such documents after they are executed.

As stated by Mr. Wilkins, there is a feeling, especially among the older and more experienced engineers, "that all disputes should not be referred to the engineer or architect, * * * the engineer or architect should only be the arbitrator as far as the character of the workmanship and the quantities or qualities of the materials are concerned. These are matters with which engineers or architects would be more familiar than any court or outside arbitrator; but there are other disputes which might arise concerning the terms of the contract, which the engineer or architect, being in a certain sense the employee of one of the parties, should not, in justice to himself, be called on to decide, unless by a special agreement of both parties." Having first recognized defects calling for a solution, it then becomes a matter for careful study to devise the most practical remedy.

The writer has tried, for a number of years, to inform himself of the various difficulties encountered by engineers and architects with construction contracts, and the solutions which have been put forward to correct them. The result of this study, as previously stated under the heading, Historical Summary, was that the documents adopted by the Royal Institute of British Architects and the Institute of Builders,

Mr. Bamford.

after some 28 years of labor, are the most practical and equitable within the writer's knowledge, and the satisfaction given by these documents after many years of use decided him to accept them as a foundation upon which to build a set for American practice. The best possible test, of course, is experience through use. The main features of the forms suggested in this paper have thus had in Great Britain the test of critical study and actual use for many years, and the principles of the suggested forms, therefore, can be accepted with greater confidence as to the practical effect of many apparently revolutionary provisions.

In order to obtain certain definite and official information about the forms for contract documents approved by the British organizations, the following questions were submitted to the Royal Institute of British Architects, the Institute of Builders, and the National Federation of Building Trades Employers of Great Britain and Ireland:

"(1.) Reference to any printed reports (or blue books) by your Institute of the reasons for reaching the conclusions as given in the forms recommended for use.

"(2.) The experience with the documents as finally adopted, in the fulfillment of their desired mission, as shown by the extent to which they are used, and reference to any lawsuits which may have given important judicial interpretations of their provisions.

"(3). The effect of arbitration in general, and your clause in particular, as a means for equitably settling differences arising between owner and contractor.

"(4.) Have any important modifications been proposed to the documents approved in 1903, or are they now considered to be generally satisfactory?

"(5.) Are the documents used (in principle) extensively by any of the government departments, and have such departments expressed themselves in any reports concerning these documents?"

The following replies were received:

"ROYAL INSTITUTE OF BRITISH ARCHITECTS.

"LONDON, 22nd February, 1910.

"DEAR SIR: I have to acknowledge in the same letter your two communications of November 19th, 1909, and February 5th, 1910, with regard to the Royal Institute Form of Contract. I regret that the exigencies of Committee work have been responsible for some delay in collecting the information for which you ask. Our Practice Committee has now considered your letter, and with the approval of our Council I send you the following information:

"1. The Practice Standing Committee does not issue reports or other particulars as to their reasons for the conclusions represented by the forms recommended by them. The Form of Building Contract issued by the R. I. B. A. is the result of careful compilation made by the Council in negotiation with the heads of the Building Trades in

Mr. Bamford.

this country and in consultation with Solicitors and Counsel upon legal points.

"2. The Form of Contract is extensively adopted in this country, the average sale being about 10 000 copies a year. Lawsuits have taken place as regards works in which the R. I. B. A. Form was used as the Contract, but the cases have not (as far as is known) been collected, and they have not been such as to render alterations in the Form of Contract necessary in the opinion of the R. I. B. A. except as hereafter stated in reply No. 4.

"3. It is believed that the clause (No. 32) relating to Arbitration is just and equitable, and that it has been found to work satisfactorily in practice.

"4. Some modifications have been made from time to time since 1903, the latest being an alteration in Clause 30, resulting on a judgment in the case of Goddard & Ferguson in which the responsibility of the Architect was dealt with. A question is moreover under consideration at the present time as to whether Clause 27 should not be altered so as to make it clear that 'P. C.' items shall be dealt with by the Architect as in 'Provisional Sums.'

"Suggestions have been made from time to time that the Form of Contract is capable of amendment and improvement, but the difficulties and disadvantages attending that course, particularly in the matter of the concurrence of the representatives of the Building Contractors, are such that it has not so far been considered expedient to adopt them, except as above stated.

"5. The R. I. B. A. Form is not, as far as is known, used by the Government departments, they having special forms for their works adapted to their own requirements.

"I have to thank you for sending me a copy of your valuable Paper on the subject, and for your promise to send me additional information in due course. Our Practice Committee will be very glad to receive this.

"Believe me, faithfully yours,

"IAN MACALISTER, *Secretary.*"

"THE INSTITUTE OF BUILDERS.

"LONDON, 7th December, 1909.

"DEAR SIR: I have to acknowledge the receipt of yours of the 19th ultimo with reference to your proposed paper upon Building Agreements, which was laid before my Council, and I am instructed to send you a copy of the Contract and to reply that there is no printed report or blue book in existence in connection with this Institute giving any detailed reasons for the conclusions embodied in the form of contract. Agreement as to the conditions was only arrived at after negotiations, conferences, and meetings, extending over a prolonged period of something like 28 years. The main reason was, of course, the desire for uniformity. Prior to the adoption of the agreed form this Institute had its own form, the various Architectural Societies had their own forms, and also many individual Architects had their particular private forms.

"Experience seems to have proved the agreed form to have been as successful as could reasonably have been anticipated, and its gen-

Mr. Bamford.

eral and increasing adoption seems to confirm this. It has been seldom before the courts, and no very important judicial pronouncements have been recorded affecting its provisions.

"As to the effect of arbitration in general, opinion is somewhat divided, largely perhaps because of the favorable or unfavorable nature of the issue to the contending parties. It is possible that not so much importance is attached to the principle now as formerly, as a means for settling differences amicably, but there is no doubt as to the beneficial effect the existence of such a provision in the building agreement has in modifying the tendency in some quarters to undue arbitrariness.

"Only one modification, and that of minor importance, has been made. It consists of an alteration in the wording of Clause 30 by substituting for it the words:

"'The Contractor shall be entitled under the certificates to be issued by the Architect to the Contractor, and within.....days of the date of each certificate, to payment by the Employer from time to time by installments, when, in the opinion of the Architect, work to the value of ..... (or less, at the reasonable discretion of the Architect) has been executed in accordance with the Contract at the rate of ..... per cent. of the value of work so executed in the building, until the balance in hand amounts to the sum of ..... after which time the installments shall be up to the full value of the work subsequently executed. The Contractor shall be entitled, under the certificates to be issued by the Architect, to receive payment of ..... being a part of the said sum of..... when the works are practically completed, and in like manner to payment of the balance within a further period of ..... months, or as soon after the expiration of such period of ..... months as the works shall have been finally completed, and all defects made good according to the true intent and meaning hereof, whichever shall last happen. The Architect shall issue his certificates in accordance with this clause. No certificate of the Architect shall of itself be considered conclusive evidence as to the sufficiency of any work or materials to which it relates so as to relieve the contractor from his liability to execute the works in all respects in accordance with the terms and upon and subject to the conditions of this agreement or from his liability to make good all defects as provided thereby.'

"I regret this Institute does not publish any reports of its proceedings or I should have had pleasure in forwarding them to you. I am desired to say, in conclusion, that a copy of your paper, when printed, would be greatly esteemed.

"I am, dear sir, yours faithfully,

"T. COSTIGAN, *Secretary.*"

"THE NATIONAL FEDERATION OF BUILDING TRADES EMPLOYERS OF GREAT BRITAIN AND IRELAND.

"LONDON, 14th December, 1909.

"DEAR SIR:

*"Form of Contract for Building Agreements.*

"In reply to yours of the 19th Nov. the form of Contract agreed upon by the R. I. B. A., the Institute of Builders and this Federa-

Mr. Bamford.

tion, which is the one to which I presume you refer, was negotiated between the two former bodies, this Federation being really represented in the negotiations by the Institute. I understand you have addressed a similar enquiry to my colleague Mr. Costigan, the Secretary of the Institute of Builders, and to him I must refer you for an answer to your query No. 1.

"As regards 2. The active propagation of the use of the agreed forms of contract rests chiefly with this Federation, which continually recommends its branches in all parts to urge their members as far as possible to sign no other form of contract. In the better organized parts of the Country this is done, in the less well organized parts the form is not much used as yet.

"Wherever opportunity occurs the local Association belonging to this Federation tries to induce local Authorities to adopt this form of contract, there is, however, no very marked success yet to record. If you get from the R. I. B. A. a statement of how many forms they sell in a year (we buy from them), you will be able to arrive at a fair opinion of the extent of use, and if they give you the information for the past 5 or 6 years you will be able to gauge the rate of progress.

"3. The effect of arbitration as a means of settling differences is generally regarded as satisfactory, in this Country, the gravest fault found with it is its heavy cost at times especially when rival experts are employed.

"Our arbitration clause has worked satisfactorily so far as I know.

"4. No important modifications have been proposed. A slight verbal amendment to Clause 30 was agreed to lately in the interest of clearness. The document is regarded by this Federation as being a satisfactory compromise.

"5. A few local authorities, I believe, use the documents in principle, but I am unable to give you any particulars as to the extent of such use; there is no information available.

"References to this question appear from time to time in our half yearly reports, but I do not think you would find them of any use for your purpose, as they are of quite a general character, and are largely covered by the replies given above.

"Yours faithfully,
"A. C. WHITE, *Secretary.*"

There is unquestionably a need for a better understanding, between owners, engineers, and contractors, of their rights, duties, and obligations in construction contracts. At present nearly every engineer is a law unto himself, and many place in contracts all sorts of unusual and too often unjust provisions. The endorsement of a carefully considered form of contract by this Society would assist materially in establishing an equitable code of procedure in construction contracts which would be one of the most practical means of avoiding many of the present unnecessary troubles.

At first reading it may seem that the suggested forms are too verbose, and could be simplified materially. The writer's aim has

been toward simplification, though the fact may not be evident, but he would strongly urge a study of the discussion relative to the British forms, in the *Journal* of the Royal Institute of British Architects, before any vital simplification is undertaken. Mr. Bamford.

## Systems of Contracting.

Any system of contracting, if based on the principles of justice and equity, must legally assure to the owner that he can demand and obtain the work for which he pays, and assure to the contractor that he can obtain definite payments for work properly done.

Messrs. Waddell, Polleys, Moore, and Allen have objected to the writer's advocacy of lump-sum contracts. There are undoubtedly conditions where some one of the various systems is superior to the others, and no one system can be found that will be the best for all classes of construction work. To prevent repetition, the writer would suggest a re-reading of the subdivision "Systems of Contracting." He has endorsed the lump-sum system as theoretically the best for contracts for the erection of buildings, and has stated that:

"Such a system presupposes that the contract defines the work to be performed, and that a contractor, therefore, can determine accurately what the execution of such work will cost.

* * * * * * *

"Many of the most serious objections to the percentage system have been overcome in varying degrees under Systems 3, 4, 5, and 6. These systems have much to commend them, and, with all their faults, they will eventually supersede the lump-sum system, unless more care is taken to make contracts complete and accurate."

The writer recognizes the gross injustice to contractors in the majority of present-day American lump-sum contracts; he also recognizes the inherent defects of the various percentage systems, from an owner's viewpoint. He also concedes that a number of firms, who are now strongly advocating percentage systems, are building reputations and achieving the maximum of success under such systems. He believes, however, that percentage systems have vital defects, due to inability to get the maximum of work out of the mechanics. The success of the few companies at the present time with percentage systems cannot be duplicated by the average contractor, and, therefore, such systems are not adaptable for general use. A careful study of the various defects in the different systems will eventually result in evolving a system which will be beneficial to both owner and contractor.

The unit price system, used so successfully by Mr. Waddell, will undoubtedly work well in railroad and other work, where the different elements which must be considered are relatively small. For building construction, the logical outcome of the unit price system is the

Mr. Bamford.

English "Quantity Surveying," which is too cumbersome for present American practice. The permanent schedule of the Home Office of the British War Department contains 4 441 numbered items of unit prices, and, even with this amount of detail, it has not been found to work successfully except for contracts of less than about $500.

The Form of Agreement and Conditions of Contract suggested herein can be used for any of the various systems by inserting in Article III the proper clause regarding payment for work, and, possibly, by making a few minor changes elsewhere. It should be noted that, if the specifications and drawings are prepared with reasonable care, so that a person of average intelligence can determine the work to be done by the contractor, the suggested Conditions of Contract provide for the usual difficulties encountered with lump-sum contracts. The Royal Institute of British Architects and the Institute of Builders have found such documents to be practical in actual use, as stated in their letters, previously quoted, and there is every reason to assume that similar documents, modified to suit American practice, would be as successful in this country.

### Practical and Equitable Contracts.

It is gratifying to note Mr. Brown's statement that one of the largest offenders—the United States Government—is sincerely trying to prepare more equitable contracts.

The work being done by the American Institute of Architects, as outlined by Mr. Boring, deserves hearty commendation, as it shows an awakening among architects to the injustice of far too many contracts, and the need for devoting more attention to the preparation of such documents. The writer is familiar with some of the preliminary work of this committee, as he received a copy of one of the preliminary reports, with a request to criticize it. He offered to co-operate with the committee, but, after an exchange of courtesies, it was considered that co-operation would not be advisable. The writer expects to be one of those who, in the words of Mr. Boring, will "criticize it voluminously," but such criticism will apply to the specific wording adopted by the committee rather than to the spirit of fair play which distinguishes their prospective documents from the "Uniform Contract" adopted and still approved by the American Institute of Architects. The "Uniform Contract" has too long been the guiding star for architects in their relations with contractors. It is hoped that the work of obtaining more equitable contracts, already so well begun by the American Institute of Architects, will be carried to its logical conclusion, and that eventually there may be some co-operation in the preparation of such documents by the two societies.

### Bonds on Contracts.

Mr. Bamford.

The writer endorses Mr. Waddell's statement as to the value of bonds on contracts. Such bonds, especially of surety companies, must be carefully read before acceptance, as they are apt to place restrictions and conditions on their responsibility, so that an owner may be unable to collect in case of default. The writer prefers to refer, in his Invitation for Proposals, to a bond to be executed similar to one attached to the documents of the particular contract, and, in the Proposals submitted, have the contractors agree to execute such a bond. When the contract is executed, the bond, attached to the contract as a separate document, is then executed by the contractor. It is, therefore, unnecessary to refer to the bond in the conditions of contract, as such reference is really not a part of the conditions.

### Agreement.

*Article I.*—Mr. Higgins suggests adding after the word, "works," in the second line, "and deliver complete," the intention being to secure a completed building rather than only such work as is distinctly contemplated by the contract documents. The suggested modification is one of those requirements which are most troublesome to contractors. The courts have held in many cases that, where the contractor agrees to furnish a building "complete" as shown on the drawings or described in the specifications, he must be responsible for all conditions and do everything required to secure a complete structure. Such a clause has often been invoked by engineers to require many thing not specified by any of the contract documents, but which may be necessary to complete the structure. This is not always a just or logical position for an engineer to take. There are many parts of a building which are not always included in the original general contract, and may later be awarded to independent contractors. Take the foundations for large work, the lighting, plumbing, and other mechanical work, interior decoration, etc.; these may be omitted intentionally in order to award them to independent contractors. Why, then, should a contractor be expected to include in his estimate everything necessary to "finish completely" a building, if such work is not contemplated by the contract documents? The justification for the theory is that there are many necessary details connected with all work which cannot well be mentioned specially, or may be too insignificant, or self-evident, and these are, therefore, legally covered by the general statement, "deliver complete."

The contractor, of course, should be required to finish completely the work for which he distinctly contracts, including all the unmentioned but necessary details, but he should not be required to assume that he must do all work which may be necessary to a com-

Mr. Bamford.

pleted building, if such work is not mentioned in the contract documents.

Sections I and II of the Conditions of Contract will serve the purpose intended by the suggested modification, will protect properly the interests of both parties, and permit questions in dispute to be adjusted on an equitable basis.

*Article II.*—The ability to get just and equitable damages in case of delay is not a simple matter. The law has drawn some very marked distinctions between damage, liquidated damage, and penalty clauses. Mr. Brown has given a very masterly discussion of many of the difficulties, using the writer's unfortunate clause as an illustration. The writer does not believe that a liquidated damage clause should be included in a standard form of contract, but should be a matter for special consideration in each contract. The writer's clause was inserted in the paper at the last moment, merely to call attention to the subject, and, in his haste, errors were made in wording which should not have occurred, as he knew better. This is an excellent illustration of the need for a carefully considered standard form of contract, to prevent just such foolish but serious errors from being made, in the final rush to put work under contract.

As stated by Mr. Bowman, the courts have held in many cases that an extension of time would act as a waiver to the collection of damages. The writer desires to give the subject more study before suggesting a clause which will answer the purpose of the usual liquidated damage clause, because such clauses do not always indicate the most equitable way of adjusting compensation for delays in completion. The writer is leaning toward the elimination of the liquidated damage clause and using instead a clause fixing the maximum liability of the defaulting contractor by reason of the items specifically mentioned, leaving to the owner his common law rights to recover for other damages, or as provided by Section XXIII, as modified. This applies particularly to building contracts where an owner may not be seriously damaged by delay in completion, but would only be put to additional expense by reason of certain known items. In many contracts—for railroads, manufacturing companies, etc.—where the completion of the work will enable the owner to earn a revenue, and is therefore essential, the lump-sum liquidated damage clause would be the one to use.

Mr. Allen's suggestion, to allow a bonus for completing the work ahead of contract time, as well as exacting a penalty for delay, is just and right for many classes of work, especially of the revenue producing class, where an owner will be directly benefited by the completion of the work ahead of contract time.

Mr. Thurston's suggested modification, for extension of time, the writer believes, is covered by Section XXIV. The suggested modifica-

tion to the liquidated damage clause is equitable, and has the writer's approval, but is open to the question of legality, as stated above and as discussed by Mr. Brown. Mr. Bamford.

*Modification of Article II.*

Omit the liquidated damage clause from the standard forms of contract, and insert a clause to suit each particular contract.

*Article III.*—The clause suggested for payment for work should not be a part of a standard form of contract, as the methods of payment will vary to suit the special conditions of each contract, and also to cover the various so-called systems of contracting given under the heading, "Systems of Contracting."

The special provisions of the California law, mentioned by Mr. Thurston, would, of course, have to be observed for work done in that State.

The suggestion by Mr. Moore, that interest should be allowed on delayed payments, has been considered seriously for many years by the writer, but legal difficulties are met in such clauses. The writer believes that the Charter of New York City allows contractors 4% on deferred payments, which is too small. Even if a contractor obtains 6%, the rate at which he must usually borrow money, the practice is objectionable, because the contractor may thus be forced to use his credit to finance the work for an owner. The owner should be held to make definite payments, and, if for any reason he is prevented, it should be a matter for equitable adjustment, as provided by Section XXXIV. It should be noted that in that section, as well as in the one of the Royal Institute of British Architects, reference to arbitration concerning certificates for payments can be made at any time, whereas, for all other matters, arbitration must be delayed until the substantial completion of the work. Under certain conditions (Section XXXIII) the contractor may terminate the contract and collect monies due.

*Modification of Article III.*

Omit from the standard form of contract the clause regarding the manner of payment, and insert a clause to suit each particular contract.

*Article IV.*—The modification suggested by Mr. Thurston has the writer's approval, but he believes that the power given to the arbitrators (Section XXXIV) would cover the condition assumed.

SCHEDULE OF CONDITIONS OF CONTRACT.

*I.—Drawings and Specifications.*—The extension of time, suggested by Mr. Higgins, for delay by the engineer in returning drawings is covered by Section XXIV.

Mr. Bamford.

*III.—Copies of Drawings and Specifications.*—Mr. Thurston's objection to the number of copies allowed the contractor is well taken, but the contractor or owner should pay for additional copies required, beyond a definitely agreed number, and not force the engineer to bear this expense.

*Modifications of Section III.*

Omit the second sentence, beginning on line four, and insert in lieu thereof, "One copy of all full-sized details and —— copies of all other drawings and of the specifications shall be furnished by the Engineer free of cost, to the Contractor, for his own use; also such additional copies, at cost, as may be necessary for the proper execution of the works."

In the next to the last line, omit "of making," and insert in lieu thereof, "he receives."

*IV.—Conform to Laws, Regulations, Etc.*—Mr. Thurston believes that the owner, or his engineer, and not the contractor, should obtain the permit for the erection of the building. This is the writer's practice, and his experience is that building laws require the owner to obtain such permits; therefore, according to the last sentence of the section, the owner and not the contractor would be required by the contract to obtain such permit. The owner, of course, should be responsible for obtaining the original permit to build, otherwise he might be trying to force a contractor to erect a building which is contrary to the building laws. In order to prevent any question arising, the following modification is suggested:

*Modification of Section IV.*

In the next to the last line, after "licenses" and before "give," insert "except the permit for the erection of the building, and shall."

*VII.—Assignment of Contract.*—Mr. Thurston's objection to this section raises the perplexing question of the status of the sub-contractor on the work. The writer's practice, which he considers equitable, is as suggested by Mr. Thurston, namely, to require contractors to submit a list of their prospective sub-contractors before the execution of the contract. The contract is then awarded, with a distinct understanding as to which of those on the list submitted would not be satisfactory, and the contractor is permitted to revise or modify this list of sub-contractors, in order to overcome any objections before the contract is executed. It is the writer's experience, however, that a contractor is seldom prepared to name more than his principal sub-contractors, and these sub-contractors usually again sublet portions of their work, and so on, down to the seventh and eighth degree. It is the writer's prac-

Mr. Bamford.

tice, therefore, to place it in the power of a contractor to have all his sub-contractors, sub-sub-contractors, etc., passed upon before the execution of the contract. If, for any reason, he does not do this, he should not object to the reservation to place a disapproval, for good reasons, upon sub-contractors selected after the execution of the contract.

In theory the engineer or owner should hold the general contractor alone responsible, and ignore entirely the sub-contractors. The writer's experience has amply justified his practice of requiring the principal sub-contractors and as many others as possible to be passed upon before the execution of the contract; and, after the execution, reserving a veto power. Such power can be, and probably has been, greatly abused, but, with the final redress to arbitration, the writer has not been able to devise a more equitable method for both owner and contractor.

*Modification of Section VII.*

Omit the last sentence and insert in lieu thereof, "No sub-contractor shall be employed of whom the Engineer has made written objections, within a reasonable time after notification, and the Contractor shall assume full responsibility for all his sub-contractors."

*VIII.—Work by Other Contractors.*

*Modification of Section VIII.*

In the next to the last line, omit "his" and insert in lieu thereof "their."

*IX.—Materials, Etc., to Conform to Specifications.*—Mr. Thurston's modification of this section is accepted.

*Modifications of Section IX.*

In line four omit "furnish him with vouchers to prove," and insert in lieu thereof, "prove to his reasonable satisfaction by vouchers or other data."

In line five, modify the words "also furnish" to read "also, as required, furnish."

*XII.—Clerk of Works.*—The writer agrees with Mr. Thurston that this section would seem to be unnecessary, as the contract is assumed to recognize only the "Engineer." There have been, however, too many cases in which there has been conflict, and repudiation of orders received from Assistant Engineers, Resident Engineers, Superintendents of Construction, etc., who are apparently vested with authority by the "Engineer" to act in his name, but who, later, may be found to lack such authority, except to a limited extent, not known to the contractor. This applies more particularly to large corporations. Experience, therefore, seems to justify this specific provision in a contract.

Mr. Bamford.

An interesting statement of experiences is contained in the paper and discussion* on "Precarious Expedients in Engineering Practice," by John Hawkesworth, Assoc. M. Am. Soc. C. E.

*XIII.—Work to be Opened Up.*—Mr. Thurston's objection to this section would seem at first glance to be well taken, but the writer believes that other sections will offset the objection raised.

There are many times when, without any inconvenience to the contractor, work at a particular place could be suspended to permit the installation of work by other contractors, or a study of the situation by the engineer. Usually, of course, a contractor will offer no objection to a reasonable delay. Many cases have arisen in the writer's experience where friction or rivalry between independent contractors on the work has necessitated ordering a cessation of work temporarily at a particular point until other contractors could install their work in a reasonable time. This, of course, was in the interest of the whole work, and seldom caused any material inconvenience to the contractor delayed, although the friction between the two contractors was openly acknowledged and the work would not have been delayed by either one to assist the other if he could have prevented such delay. The Royal Institute of British Architects has a similar section, so that apparently, it has encountered similar difficulties. Should the engineer arbitrarily injure the contractor by delaying the work, there would seem to be plenty of legal redress under Section XXIII-A, Contractor's Claim For Damages; Section XXIV, Extension of Time; Section XXXIII, Termination of Contract by Contractors; and Section XXXIV, Arbitration.

*Modification of Section XIII.*

In line two, change "within such times" to "within such reasonable times."

*XV.—Defective Work.*—Mr. Thurston does not object to the contractor being required to make good any defects arising within a stated time after completion, but he objects to placing the clause, "any damage to pointing by frost appearing within the like period," in the conditions of contract rather than in the specifications. In all cases the contractor should be responsible for the pointing for as long a time as for the other defects. He believes, therefore, that it should be included in the conditions of contract, and may be repeated in the specifications, if desired.

*XVI.—Copy of Quantities, Etc.*—Mr. Allen's remarks, about the possible abuses by engineers in the uses made of contractor's quantities, are pertinent, and the writer has tried to minimize in this section the

* *Transactions*, Am. Soc. C. E., Vol. LXVII, p. 32.

Mr. Bamford.

most serious objections to such requirements. It should be noted that the section requires statements "for each general item of work," and that "the above schedule shall be for the use of the Engineer, at his discretion, only in preparing estimates for payments on account to the Contractor." It is not intended that an engineer should demand, under this section, a detailed statement which he could later bring forward as a lever with which to force a contractor to alter any subsequent estimates. The writer's practice is to require such a statement after the contractor has been tentatively selected and before the contract is executed. Then such schedules cannot be used to influence the various other bidders to alter their estimates (for private work), as has been sometimes stated, after the bids are opened and before the contract is executed. The engineer is thus able to obtain from the contractor a satisfactory schedule, and the contractor is assured that it will be used for its legitimate purposes only. Such a schedule is not intended to serve the same purpose as the British "Schedule of Quantities."

*XVII.—Variations and Extras.*

*Modification of Section XVII.*

Alter the last sentence to read: "Any such variation or extra is hereinafter referred to as an authorized variation or extra."

*XVIII.—Price for Extras.*—The remarks of Messrs. Waddell, Thurston and Allen are interesting, as showing different practical views of the merits of unit prices. The writer has also commented briefly on the subject under "Systems of Contracting."

It would seem that, in principle, the four methods of payment suggested for extras should cover equitably the difficulties encountered in the adjustment of variations and extras, and special consideration is requested for the original section, as herein modified.

*Modifications of Section XVIII.*

At the end of the first paragraph insert "The amount to be allowed on either side in respect of the variations so ascertained shall be added to or deducted from the contract sum, as the case may be. In variations involving the omission of work, the amount to be deducted for such omission shall be based on the net cost, as given under *'C,'* plus ....% for prospective profit."

Under *"C,"* first line, change "will" to "shall."

In line seven, under *"C,"* omit "actual cost" and insert in lieu thereof, "net cost when new."

In line ten, under *"C,"* insert after "conclusively" and before "that" the words, "to the reasonable satisfaction of the engineer."

Omit the last sentence under *"C."*

Mr. Bamford.

*XIX.—Damage to Persons and Property.*—The writer frankly admits that this section has been a thorn in his flesh for some time. Mr. Wait's criticism has his hearty approval. It would seem to the writer that for political or other reasons, false liens can be placed on property to harass the contractor, and he can see no legal way to overcome the difficulty by any provision of the contract. Let us assume that a self-evident false lien is placed on a building, the owner is then legally responsible if he makes further payments to the contractor. The case is delayed and delayed and finally comes to trial by jury. (Juries have been known to render most peculiar verdicts.) If the lien is sustained and judgment awarded, the owner alone is held for payment. It would seem, therefore, as long as there are mechanics' lien laws which permit action being taken against the owner and the property, that the only safe course for an owner to take or an engineer to recommend, is to require contractors to bond any liens placed on the property, or else withhold a sufficient amount of money due the contractor to cover the threatened lien.

Mr. Wait objects to the phrase "caused by or alleged to have been caused by." This undoubtedly may cause hardship to a contractor by reason of alleged claims. On the other hand, what protection has an owner if claims, no matter how flagrantly unjust, are "alleged to have been caused" by the contractor? It would obviously look as if the contractor and not the owner should be the only one who could properly defend such claims and prevent judgment being taken against the owner. Any equitable and legal solution of the injustice which can be caused by false claims would be welcome.

Various liability companies issue policies by which they indemnify the owner and contractor against any and all claims or alleged claims. At present this seems to be a practical way out of the difficulty, as the premium would be charged against the owner by the contractor in his estimate. The writer has often suspected that probably the liability insurance companies were fostering the necessity for contractors to obtain liability insurance. The recent disclosures in the insurance investigation in New York by the Superintendent of Insurance have not tended to allay this suspicion.

The section suggested by the writer has always seemed to him to be unnecessarily verbose, and he has often used a clause similar to that suggested by Mr. Thurston. The section suggested, however, was prepared, revised, analyzed, dissected, approved, and recommended by some of the ablest members of the New York bar for the use of a large corporation for which the writer has prepared many contracts. Every time he has suggested modifications or simplification he has been met with most plausible arguments from prominent lawyers who insisted that justice to both contractor and owner could only be secured

by the section as given. The writer, therefore, has given it as being recommended by most eminent authority, but he has always had a secret feeling that it could be legally simplified without losing its effectiveness. For the present, however, he will leave to others the pleasure of offering legally correct modifications. Mr. Bamford.

*XXIII.—Damages for Delay.*—The writer agrees with Messrs. Bowman and Allen that the contractor should be entitled to obtain damages as well as to pay damages due to delays incident to the work. The illustrations cited by them are striking and instructive.

Through an oversight, a section, intended to recognize the contractor's right to damages, was omitted from the paper. This section was:

*XXIII-A.—Contractor's Claim for Damages.*—Should the Contractor be damaged by the act, neglect, or default of the Owner or the Engineer, then the amount of said damage shall be determined and awarded by the Engineer, subject to arbitration; provided, however, that no allowance shall be made unless a written claim therefor be presented to the Engineer as soon as reasonably possible after the occurrence of such damage.

Mr. Bowman's statement, that an extension of time provides the exclusive remedy to a contractor, should be considered carefully. When provision is made for extension of time, liquidated damages, and damages to a contractor, the question may well arise: Which should take precedence in a particular case, and what interpretation might the law place on such provisions? The writer desires to consider the question more thoroughly. He feels, however, that provision for liquidated damages should be omitted from many contracts, and an attempt made to have requirements which will grant a fair and reasonable extension of time or proper damage when an extension of time would not afford equitable redress.

The last clause should be omitted, as it will conflict with a liquidated damage clause, should one be used, as stated clearly by Mr. Brown.

*Modification of Section XXIII.*

Omit the last paragraph.

*XXIV.—Extension of Time.*—Mr. Thurston objects to the use of the foreign phrase, *"force majeure,"* as not being as clear as the English language can make it. Modern jurisprudence, both English and American, still uses many Latin phrases because they express more tersely a well-established legal meaning than their equivalent English translations. For the same reason English jurisprudence has held fast to many French expressions, of which *"force majeure"* is one. The English translation would probably be given as "forces beyond

Mr. Bamford.

our control." Many recent American judicial decisions would indicate that the English translation is not as well established in the eyes of the law as is the French phrase in English jurisprudence. For the sake of brevity and legal clearness, the writer prefers, for the present, to retain the phrase, "*force majeure.*"

Mr. Bowman's statement, that an extension of time has been held to prevent a contractor from recovering damages, should be seriously considered. The writer has partly treated this subject under the preceding section. It would seem that, by a modification of this section, requiring a contractor to apply for an extension of time, the difficulty might be adjusted satisfactorily. With such a proviso, if a contractor applies for an extension of time under this section, he would be precluded from also demanding damages under Section XXIII-A, and if he demands damages under that section, he would then be precluded from also demanding an extension of time. The engineer would make his award on the claim as made, and either the owner or contractor, if dissatisfied, could have the privilege of taking an appeal to arbitration.

*Modifications of Section XXIV.*

In line fourteen, insert "shall" in place of "will."

In line fifteen, at the end of the sentence, add "unless the Contractor shall have made claim for damages for such delay in accordance with Section XXIII-A, provided, however, the Contractor applies for such extension of time as soon as reasonably possible after the occurrence of the delay."

*XXIX.—Sub-Contractors.*—Objections are often made that the contract between the owner and contractor provides no security to a sub-contractor, and it is contended that the contract should provide such protection. The sub-contractor is legally responsible to the general contractor, and it is to him that he must look for redress, except as is otherwise provided by mechanics' lien laws.

Sub-contractors neglect too often to have a written contract with the general contractor; or, in many cases, they use the form intended for a direct contract with an owner. The forms suggested in this paper, as well as the majority of other forms, are not intended for use between contractors and sub-contractors. Mr. Bowman's statement is a timely warning to sub-contractors.

*XXX.—Payment and Certificate.*—Mr. Lowinson believes that the engineer should not be required to make a search for liens, but that the owner should do so.

Section XXX does not require that the engineer shall make a search for liens, but merely provides that the evidence of a lien is a

Mr. Bamford.

legal reason for the engineer to withhold such a proportion of a certificate otherwise due as will cover such lien until it is paid or bonded. Under Section XXXI, Liens, the owner is also authorized to withhold from money due an amount sufficient to cover any liens.

The power reserved to an engineer to withhold money for liens of which he has received knowledge is sometimes very desirable, especially where working for large corporations. The writer's practice, also as suggested by Mr. Lowinson, is for the engineer to issue his certificate for the amounts due and to stamp across the face, "make search for liens." The owner then makes the search for any liens, and withholds payment for an amount to cover them.

*XXXI.—Liens.*—The objections by Messrs. Wait, Thurston, Lowinson, and Moore have been answered under Section XIX, Damage to Persons and Property.

A lien against property, whether false or true, legally stands against the owner until bonded or removed. If the owner pays the contractor he takes a great risk, because the contractor will then lose his vital interest in opposing the false claim, and he is usually the only one who can offer a satisfactory defence, the owner lacking the necessary information or documents. Therefore, if the contractor is paid and the false claimant pushes his suit to trial, the owner is likely to lose and to be forced to pay the false claimant.

The writer would welcome any legal remedy which would protect properly both the contractor and the owner against a flagrant abuse of the lien laws, especially for spite or political purposes.

The suggested modification by Mr. Thurston would not, in the writer's opinion, serve any useful purpose, because he knows of no legal means which an owner can take to pay a contractor and also protect his own interests, except by bonding such claims. Any false liens can be removed from the records much better by the contractor than by an owner.

*XXXIII.—Termination of Contract by Contractor.*—Under Section XVIII, Price for Extras, a modification allowing a contractor a percentage for prospective profit on modifications involving the omission of work is suggested.

While recognizing the justice of Mr. Thurston's suggestion, regarding the allowance for anticipated profits to a contractor by reason of the termination of the contract, the writer believes that this section, with the possibility of a claim for damages under Section XXIII-A, and appeal to arbitration under Section XXXIV, is as far as it is legally and equitably advisable to go at this time. On a large contract, which might be terminated shortly after it was started, the anticipated profits might be out of all proportion to the amount which a contractor might reasonably be expected to receive. There would also

Mr. Bamford.

be too great an incentive for a contractor, who early recognized that he had not made a good bargain, to work around to a termination of the contract, in order not only to devote his attention to more profitable work, but also to collect alleged anticipated profits.

The courts have not looked with favor on the majority of claims for anticipated profits. More justice to both parties might be secured if the contractor claimed damages under Section XXIII-A.

*XXXIV.—Arbitration.*—Mr. Thurston's objection, that the provision relating to the appointment of an arbitrator, in certain cases, by the President, for the time being, of the American Society of Civil Engineers or the American Institute of Architects, would be impractical outside of the vicinity of New York City, does not meet the writer's views. Both these organizations are National in scope, and their Presidents are selected from the country at large. It is the character of such representative men, and not the mere incident of their place of residence, which would assure their appointing an arbitrator fitted to handle a case in the locality of the contracting parties.

The writer regrets that Mr. Wait should have interpreted this section as conferring the right to appeal any or all subjects at any time, rather than as limiting appeals to only those matters to which exception was taken within a reasonable time after the engineer had rendered a decision. The section states, in the first and third paragraphs, " * * * then either party shall forthwith give to the other notice of such dispute or difference, and such dispute or difference shall be and is hereby referred * * *. Such reference, except on the question of certificate, shall not be opened up until after the completion or alleged completion of the works, unless with the written consent of the Owner or Engineer and the Contractor. The arbitrator, or arbitrators, shall have power * * * to determine all matters in dispute which shall be submitted to him or them, and of which notice shall have been given as aforesaid * * *." These provisions follow those of the Royal Institute of British Architects, and, the writer trusts, overcome Mr. Wait's objection.

Mr. Wait's criticism of the usual practice of having three arbitrators, and his endorsement of referring questions in dispute to a single arbitrator, have the writer's entire and enthusiastic support. In preparing this section the writer had in mind the general American leaning toward three arbitrators, rather than to only one, and he felt constrained to arrange the clause to suit all classes and conditions of men. It should be noted that the section as given provides first for the appointment of three arbitrators to be nominated by the contracting parties in the usual way. They can thus have the usual and cumbersome three if they desire. They may, however, by mutual consent, nominate a single arbitrator. Should either one prefer a single arbitrator he has only

Mr. Bamford.

to refuse to nominate one of the three arbitrators, and, in the event of his failure, the reference is then submitted to one of the two single arbitrators agreed upon at the time of executing the contract and for which blanks are provided in the forms. Should either of these men fail or be unable to act, or should the blanks not be filled at the time of the execution of the contract, then a single arbitrator shall be appointed by the President, for the time being, of the American Society of Civil Engineers, or the American Institute of Architects. The writer feels, therefore, that he has covered almost every contingency except a national catastrophe, and that any contracting party could secure the appointment of a proper judge to review his disputes. Having now given a universal-panacea arbitration clause, the writer will, in his modification, offer a substitute clause providing only for a single arbitrator. This modified clause follows more closely the one approved by the Royal Institute of British Architects, which is given in full in the paper.

The writer heartily endorses the opinion of Messrs. Wait and Waddell that the only way to insure that both parties will carry out the provisions of an arbitration clause is by requiring them to give a bond for faithful performance. It must be understood, however, that the writer endorses this bond because the laws of most of our States do not contain provisions similar to the English Arbitration Act 1889, which legally compels observance of arbitration clauses, as will be shown later.

In reading judicial decisions, as well as comments by lawyers and engineers, the writer has been surprised to see that there seems to be an almost unanimous opinion that, in the United States, arbitration clauses will never be upheld, because they are always intended to act as a final decision and thereby deprive the courts of their inalienable rights of review under the Constitution. The discussions by Messrs. Wait, Waddell, Wilkins, Ruggles, and Lowinson also seem to be to the same effect.

In view of the almost unaminous opinion that there are constitutional limitations to a proper solution of the various technical questions by means of arbitration clauses which cannot be repudiated at will, the writer is especially timorous about presenting his personal views.

The fundamental principles of English and American jurisprudence are the same; there is an English Arbitration Act 1889; letters (previously given) from the Royal Institute of British Architects, the Institute of Builders, and the National Federation of Building Trades Employers of Great Britain and Ireland all state that the English statute is reasonably satisfactory in its operation; therefore, why cannot a similar statute work with equal satisfaction in any of

Mr. Bamford.

our States? The writer believes that it can, but that the principles underlying the English act are not fully appreciated in this country.

The English act, therefore, can safely be taken as a legal model for adoption by the various States where it is desired to make arbitration as successful a means as possible for adjusting many technical disputes.

In order to obtain a better understanding of some of the excellent provisions of the English Arbitration Act 1889, the writer has selected extracts from the standard work on Arbitration by Professor Bannister Fletcher.*

"In order to assist the reader in arriving at a clear understanding of our subject, we propose to consider, first, how arbitrations may arise. *The Modes of Arbitration* may be divided into three classes:

"*1.* By order of a judge, or of the Court, before or in the course of trial.

"*2.* Under one of the especial Acts of Parliament which provide for the settlement by arbitration of disputes arising under them.

"*3.* By consent of the parties.

"*1. By Order of a Judge or Court.*—Nothing is more common, in an action involving technical questions after the judge, jury, witnesses, counsel, and solicitors are assembled, the pleadings opened, and the first few introductory sentences spoken by the counsel for the plaintiff, than for the judge to suggest that it is really a matter for arbitration. Usually, after this expression of opinion from the Bench, the case is at once referred, and the arbitrator not unfrequently nominated by the judges. (See Sec. 14 of the Act.)

* * * * * * *

"The reference under Sec. 14 is a reference for trial, and the order can be made either before the case gets into Court or in Court; but the jurisdiction to make the order depends on the case falling within (*b*) or (*c*). If the case does not fall within these sub-sections, the order can only be made by consent of the parties under (*a*). The jurisdiction is also subject to the right given to the parties under certain cases of having a trial by jury. (See Order of Supreme Court XXXVI, Rule 6.)

* * * * * * *

"*3. By Consent.*—The third (and certainly in our opinion the best) mode in which arbitrations may arise is by consent of the parties. We say advisedly the best mode, because hereby is saved all the enormous cost of preparing for trial, which, if, as is probable, the case is after all referred, is entirely thrown away. It must, therefore, often be advantageous to agree at the outset to settle any differences by arbitration.

"Among matters which may be agreed to be referred are also any 'future differences' which may arise between parties, although none at present exist. Thus parties may give the arbitrator power to determine on contingent claims, or on matters in dispute, or demands arising after the date of submission.

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* See Bibliographical Notes, p. 444.

Mr. Bamford.

"Formerly, a very remarkable point in connection with arbitrations was one the reason or justice of which we confess we did not comprehend. It was that neither at law nor in equity could the fact that an arbitration was pending be pleaded as a bar to an action or suit for the same demand, and this even though the submission was made a rule of a court of common law. The exceptions were when there was a covenant not to sue (which will suffice to stay proceedings in equity), or when there was an agreement that, 'in consideration of the defendant consenting to refer matters in dispute in an action, the plaintiff will accept such agreement in satisfaction of all damage in respect of certain *other matters,* and a reference thereon.' This could be pleaded as satisfaction to an action in respect of the last-mentioned matters.

"If, however, the submission contained an express stipulation that no action should be brought, the Court would, on application, stay proceedings in any action commenced contrary to such stipulation.

"Previous to the passing of the Arbitration Act of 1889 these points applied to England and Wales, but now, under Sec. 4 of the Act, it is defined that:

" 'If any party to a submission, or any person claiming through or under him, commences any legal proceedings in any court against any other party to the submission, or any person claiming through or under him, in respect of any matter agreed to be referred, any party to such legal proceedings may at any time after appearance, and before delivering any pleadings or taking any other steps in the proceedings, apply to that court to stay the proceedings, and that court or a judge thereof, if satisfied that there is no sufficient reason why the matter should not be referred in accordance with the submission, and that the applicant was at the time when the proceedings were commenced, and still remains, ready and willing to do all things necessary to the proper conduct of the arbitration, may make an order staying the proceedings.'

"The application under this section is by summons to a Master of the Supreme Court under Order LIV, Rule 12a, of the Rules of the Supreme Court. The applicant must enter an appearance to the action, but must not have delivered any pleadings or taken any other steps in the proceedings. We do not propose to enter into the question as to what constitutes 'taking any other steps in the proceedings,' as it is a highly technical matter on which there are many decisions, and it is best to take legal advice on it when the point arises. The Court has discretion as to granting the stay, and is bound to exercise it (*re* Carlisle, 44 C. D., 200; Lynn *v.* Johnson, 40 C. D., 579; Young *v.* Buckett, 30 W. R., 511; Workman *v.* Belfast Harbour Commissioners (1899), 2 I. R., 234), but, as a general rule, the Court stays the action unless the plaintiff can show good reasons why the action should go on. (Willesford *v.* Watson, L. R., 8 Ch., 480; Denton *v.* Legge, 72 L. T., 626; Hodgson *v.* Railway Passengers Co., 9 Q. B. D., 188.)

* * * * * * *

"*Revocation.*—Having now explained the various methods by which a matter may be submitted to arbitration, it will be well to consider how such submission, when made, may be revoked.

"It appears that prior to the passing of the 3 and 4 Will. IV, c. 42, the authority of the arbitrator might be revoked at any time before

Mr. Bamford.

the award was made, at the pleasure of any party to the submission, whether the submission was by agreement in writing, by bond, by deed, by judge's order, by order of Nisi Prius, or by rule of Court, and notwithstanding it was made irrevocable by the express words of the submission. The reason of this was that nothing of less power than legislative enactment could make that irrevocable which was, in the very nature of things, revocable, as the arbitrator, being appointed by the consent of the parties to act for them, could no longer act when that consent was withdrawn, and any award made subsequent to a revocation was therefore a nullity. Either of two parties to a submission, or, if there were several, any one of them, could, by revoking the authority of the arbitrator, render the submission void as to all, even against the will of his co-plaintiffs or co-defendants.

"It should be noted that the agreement to refer was never revocable, but only the appointment of a particular arbitrator. (*In re* Smith and Nelson, 25 Q. B. D., 545.) The party revoking would be liable to an action for damages for breach of the promise to perform the award. The revocation of a submission after it had been made a rule of Court was a contempt against which attachment would issue or an action lie.

"The above mentioned Act is now repealed, but the Act of 1889 provides in Sec. 1 as follows:

"'A submission, unless a contrary intention is expressed therein, shall be irrevocable, except by leave of the Court or a judge, and shall have the same effect in all respects as if it had been made an order of Court.'

"This section only applies where there is a written submission (see Sec. 27 of Act of 1889); therefore, in the cases where there is no such submission, the old law will apply. The application to revoke must be made before the award is executed. (Phipps *v.* Ingram, 3 Dow., 669.) The Court exercises its power to revoke very sparingly, and it is entirely in the discretion of the Court. (East and West India Docks *v.* Kirk and Randall, 12 App. Cas., 738; James *v.* James, 23 Q. B. D., 12; Belcher *v.* Roedean School Site, etc., 85 L. T., 468.)

"The principal grounds on which the Court has been known to revoke are—

"(*a*) The bankruptcy of one party. (Gaffney *v.* Killen, 12 Ir. C. L., Rep. App., 25; Marsh *v.* Wood, 9 B. and C., 659.)

"(*b*) Misconduct of the arbitrators, such as corruption, or receiving evidence unknown to one of the parties (Drew *v.* Drew, 2 Macq., 1), or appointing an umpire by lot (*re* European and American SS. Co., and Crosskey, 29 L. J. C. P., 155), or if the arbitrator is about to exceed his authority. (Faviel *v.* Eastern Counties Railway Co., 2 Ex., 350.)

"(*c*) Bias. (*Re* Baring Brothers and Boulton, 61 L. J. Q. B., 704; Eckersley *v.* Mersey Docks and Harbour Board (1894), 2 Q. B., 667; *Re* Donkin and Leeds Canal, 9 Times L. R., 192; *Re* Frankenberg and the Security Co., 10 Times L. R., 393.)

"(*d*) Improper admission of evidence. (*Re* Lord Gerard and London and North-Western Railway Co. (1895), 1 Q. B., 459.)

"(*e*) Improper rejection of evidence unless the arbitrator under-

takes to admit the evidence. (Hart *v.* Duke, 32 L. J. Q. B., 55; Robinson *v.* Davies, 49 L. J. Q. B., 218.) Mr. Bamford.

"It would appear that the better opinion is that in cases (*d*) and (*e*) the preferable course is not to ask for leave to revoke, but for an order directing the arbitrator to state a case for the opinion of the Court under Sec. 19 of the Act of 1889."

The sections relating to revocation in case of the death of either of the parties or the arbitrator, unless provision is made for such a contingency in the submission, have not been quoted.

The following extracts are taken from another recent work:*

"*Submission Defined.*—By Sec. 27 a 'submission' means a written agreement to submit present or future differences to arbitration, whether an arbitrator is named therein or not.

"The 'arbitration clause' in an engineering contract or any other agreement is a submission to arbitration. The object of the above provision is to sanction such a clause which appears, at first sight, to oust the jurisdiction of the Courts or, at any rate, to stay proceedings at law until the matter in dispute has been dealt with by the arbitrator. We shall see hereafter (p. 210, § 9, *infra*) what may be the effect of so ousting the jurisdiction. It should be pointed out, in this connection, that the ordinary clause in a contract providing that the engineer's certificate shall be conclusive as to the work done, is not a submission to arbitration. (See Chap. XIV, § 8.)

"*Enforcing Submission.*—The Court has full power to enforce the arbitration clause in an agreement; and the way in which the Court will exercise that power may be thus illustrated. Suppose an employer and a contractor enter into a contract, which provides that all disputes which may thereafter arise shall be referred to an arbitrator. A dispute having arisen, the employer, wholly ignoring the arbitration clause—his self-chosen tribunal—issues a writ against the contractor in the High Court of Justice. In such a case it would be competent for the contractor, before delivering any pleading or taking any other step in the action, to apply to the Court to stay the action, and the Court or Judge, if satisfied there was no sufficient reason why the matter should not be referred in accordance with the submission and that the contractor was and still remained willing to do all things necessary to the proper conduct of the arbitration, might make an order staying the proceedings. It should be noted that the jurisdiction is not ousted; the proceedings are only stayed pending the reference. (As to what amounts to sufficient reason, see *post*, § 13.)

"It should be mentioned that a reference agreement will also be enforced, although no arbitrator is actually named therein, as the Court has power in such a case to appoint an arbitrator if one cannot be agreed upon.

* * * * * * *

"*Jurisdiction of the Courts Not Ousted.*—The fact that the jurisdiction of the Courts is not really ousted, demands some further explanation. Mr. Redman in his *Arbitrations and Awards* points out that: 'It is a common practice to insert in contracts for works, covenants or

* "The Law Affecting Engineers," by W. Valentine Ball, M. A. (1909).

Mr. Bamford.

agreements providing that any difference or disputes thereafter arising between the parties shall be referred to arbitration. Agreements of this kind do not deprive the Courts of jurisdiction over the matters to be referred; nor will the addition of a covenant not to sue in respect of such matters prevent either party from bringing them into Court' (*loc. cit.*, p. 52). It is established that, on grounds of public policy, any agreement to oust the jurisdiction of the Courts is void. These views were expressed by Sir George Jessel in the case of Ripley *v.* Great Northern Railway, 1875, 31 L. T., 869.

"'But,' it may be asked, 'how is that statement of the law compatible with what now appears in the Arbitration Act, namely, the power which the Courts have to compel parties to go to arbitration?' A little reflection will show that the jurisdiction of the Court is not really ousted. It is merely provided that before seeking a remedy at law the parties have an opportunity of referring to their own tribunal, and an absolute discretion is reserved to the Court to say whether the case is one for arbitration or not.

"The way in which an arbitration clause may be a condition precedent is well illustrated by the case of Westwood *v.* Secretary of State for India, 1863, 1 N. R., 262."

Desiring to make his position clear, the writer offers the following recapitulation. He is thoroughly convinced of the advisability of having a fair and just arbitration clause in construction contracts as one of the most effective and practical means of settling disputes between the parties to a contract. At present he knows of no statute in the United States which will make binding a provision to submit to arbitration, if either party decides to repudiate it before the award is made. Therefore, until such statutes are enacted, the only successful way to ensure observance of an arbitration provision is by a bond between the parties, as suggested by Messrs. Wait and Waddell.

The English Arbitration Act 1889, with recent modifications,* is a most practical and equitable document, and, as both English and American jurisprudence have the same derivation, there is no constitutional objection to the enactment of similar statutes by our States. Such a statute would legally overcome the previous judicial decisions apparently opposing the principle of arbitration. Past attempts to deprive the courts of their jurisdiction by endeavoring to make the engineer's decision final and conclusive, rather than merely final, as to questions of fact but reviewable on points of law, etc., is unwise and harmful. The recent Pennsylvania law, referred to by Mr. Wilkins, should be repealed in favor of an act similar to the English Arbitration Act 1889, where the majesty of the courts is respected as well as the rights of the individual in his attempts to secure equity in his contractual relations.

*Modifications of Section XXXIV.*

Omit the entire section and insert, in lieu thereof, the following:

* *Engineering News*, October 8, 1908, p. 391.

Mr. Bamford.

"*XXXIV.—Arbitration.*—Provided always that in case any dispute or difference shall arise between the Owner, or the Engineer on his behalf, and the Contractor, either during the progress of the works or after the termination, abandonment, or breach of the contract, as to the construction of the contract or as to any matter or thing arising thereunder (except as to matters left to the sole discretion of the Engineer under Sections II, VII, X and XIV, and the exercise by him, under Section XIII, of the right to have work opened up), or as to the withholding by the Engineer of any certificate to which the Contractor may claim to be entitled, then either party shall forthwith give to the other written notice of such dispute or difference, and such dispute or difference shall be and is hereby referred to the arbitration and final decision of ....., or in the event of his death, or unwillingness or inability to act, of....., or in the event of his death, or unwillingness or inability to act, of a person to be appointed on the request of either party by the President, for the time being, of the American Society of Civil Engineers, or of the American Institute of Architects, whichever shall be first requested, and the award of such arbitrator shall be final and binding on both parties. Such reference, except on the question of certificate, shall not be opened up until after the completion or alleged completion of the works, unless with the written consent of the Owner or Engineer and the Contractor. The arbitrator shall have power to open up, review, and revise any certificate, opinion, decision, requisition, or notice, save in regard to the said matters expressly excepted above, and to determine all matters in dispute which shall be submitted to him, and of which written notice shall have been given as aforesaid, in the same manner as if no such certificate, opinion, decision, requisition, or notice had been given. Should either party, without reasonable excuse, refuse, or neglect, to supply the arbitrator with any papers or information considered necessary by him, which papers or information shall have been specifically demanded in writing, or refuse or neglect to attend on the reference, the arbitrator is hereby authorized and empowered by both parties to the contract to proceed in *ex parte* proceedings, and such proceedings shall be final and binding. Upon every or any such reference, the costs of and incidental to the reference and award, respectively, shall be in the discretion of the arbitrator, who may determine the amount thereof, or direct the same to be taxed as between attorney and client, or as between party and party, and shall direct by whom and to whom and in what manner the same shall be borne and paid."

### General Conditions.

Mr. Waddell, like many others, has followed the practice of making a short agreement and placing the various conditions of contract in the specifications. The question is largely one of practical expediency.

Mr. Bamford.

The writer, after much study and experimenting, prefers to endorse the English practice of attaching to the agreement a schedule of conditions of contract which thus becomes standard and can be printed for use in any contract. Then, at the beginning of the specification, place a chapter entitled General Conditions, containing other clauses special to the particular contract. It would probably be an advantage to attach an unexecuted set of the printed forms of agreement and schedule of conditions of contract at the beginning of the specification so that the superintendent and foreman on the job may be conversant with the conditions of contract.

Article V of the agreement specifically makes the conditions of contract a part of the agreement, and, for practical reasons, the writer cannot endorse Mr. Thurston's suggestion that the conditions of contract should be included within the agreement proper.

In conclusion, the writer hopes that the subject of proper contracts will be given further study by the Society, for he believes that a better understanding among engineers of the rights, duties, and obligations of the various parties interested in a contract, will produce a more satisfactory state of affairs in the execution of engineering work.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

# TRANSACTIONS

Paper No. 1148

## UNDERPINNING THE CAMBRIDGE BUILDING, NEW YORK CITY.*

By T. Kennard Thomson, M. Am. Soc. C. E.

With Discussion by Messrs. Henry Gorton Opdycke, E. A. Yates, Ogden Merrill, Oscar Lowinson, J. C. Meem, and T. Kennard Thomson.

In July, 1907, the writer was retained by Henry G. Opdycke, Assoc. M. Am. Soc. C. E., to report on the undermining of the Cambridge Building, on the southwest corner of Thirty-third Street and Fifth Avenue, New York City, by the Pennsylvania Railroad Tunnel, then under construction.

Mr. Opdycke had already made a careful survey of the premises, and also had a number of excellent photographs, from which those illustrating this paper have been selected.

Fig. 1 shows the approximate cross-section of the tunnel excavation at a point opposite this building, as taken by Mr. Opdycke and the writer. The space marked "To be back-filled" represents the approximate deviation from the theoretical tunnel lines, and shows that at one point a small cavity extended a short distance south of the building line of the Cambridge Building, or several feet farther south than was intended.

It also indicates roughly where Thirty-third Street caved in, on December 14th, 1906, in front of the Waldorf. The cave-in had been

* Presented at the meeting of February 2d, 1910.

back-filled, but the curb, the street, and the Cambridge Building had continued to settle.

Fig. 1, Plate XXXIV, shows very plainly the settlement in Thirty-third Street. The street had been flooded, and the water covered the curb, in front of the entrance and near the middle of the Cambridge Building, which was the point where the greatest settlement occurred. The tendency of the whole building, as shown by all the photographs, was to bulge toward the north, as well as to settle vertically.

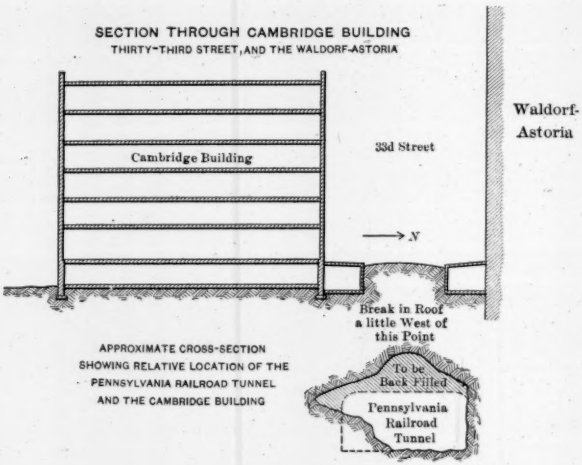



FIG. 1.

It was claimed by others that the whole trouble was caused by a defective 8-in. column just east of the entrance, but it is peculiar that, although this column had moved northward and had settled, it did not break its bed nor its connection with the brickwork of the north wall, and remained absolutely plumb.

There were a number of vertical and inclined cracks in the interior north and south walls, showing the tendency of the building to move northward and at the same time to settle vertically, the dimensions of the cracks decreasing as the distance from the curb increased; in fact, the greatest disturbance in the building itself was at the center of the north wall, and in the areaway, sidewalk, and street, as might be expected.

The connection between the two boilers in the cellar parted, break-

FIG. 1.—SETTLEMENT OF STREET, CURB, ETC., IN THIRTY-THIRD STREET, IN FRONT OF CAMBRIDGE BUILDING.

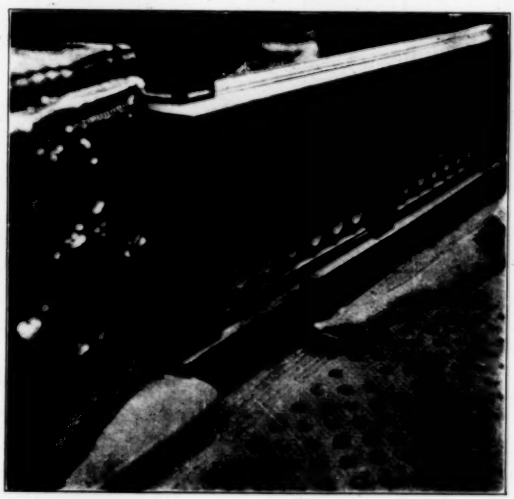


FIG. 2.—SETTLEMENT OF SIDEWALK, IN THIRTY-THIRD STREET, IN FRONT OF CAMBRIDGE BUILDING.

ing the pipe connections. Both boilers settled, the one several inches farther north than the other.

There were several cracks in the area floor, and some disturbance of the area wall, one joint alone opening up more than 1 in.

The sidewalk settled considerably, as shown in Fig. 2, Plate XXXIV; and there were some cracks. The curb was reset several times, sometimes as much as 7 or 8 in.

Fig. 1, Plate XXXV, shows some of the cracks in Kirkpatrick's Jewelry Store, in the Cambridge Building. In a number of places the joints in the marble work in the main hall opened up.

The fact that an old stream ran under the site of the Cambridge Building and the Waldorf-Astoria, also aggravated matters, especially as the break in the tunnel was at or near this old stream. The foundations of the Waldorf-Astoria had been carried down to the rock, but the east end of the Cambridge Building was founded on a spread footing of concrete and the west end on piles.

When the Cambridge Building was remodeled, in 1906, to convert it from a hotel into an office building, these piles, which were about 30 ft. long and, when driven, had been cut off below the water line, were found to be slightly above the water line, the latter having been lowered enough to expose their tops to the atmosphere, allowing them to rot.

It is known, of course, that timber will last practically forever if entirely submerged, but will soon rot out if not entirely under water. Therefore, at that time, the piles were cut off below the new water line, capped with concrete, and five heavy 20-in. I-beams, about 40 ft. long, were placed on the concrete and buried in it, making a very substantial foundation for the west end of the building.

In 1907, when Mr. Opdycke and the writer examined the tunnel, they noticed that several rather large streams of water—evidently from the old stream shown on the maps—were pouring into it at this point. The examinations showed that the building had settled considerably and was still settling, and the writer was requested to design a system of underpinning carried to rock. This he refused to do at that time, for fear of opening up a direct connection between the cylinders and the tunnel, thus endangering the entire building; but he recommended tying back the front wall with rods, to prevent it from falling away from the remainder of the building.

This was immediately done, as shown by Fig. 2. Two 12-in. beams, about 41 ft. long, were placed vertically just east of the main entrance on Thirty-third Street, which was the point of greatest disturbance. These beams extended from the areaway floor up to and slightly above the third floor. The tops of the beams were anchored back by a 1½-in. rod, about 102 ft. long, made up of stock lengths of about 16 ft., and connected with turnbuckles.

The rear or south end of the rods ran through an open court, but close to the wall. On each side of the court 12-in. I-beams, about 6 ft.

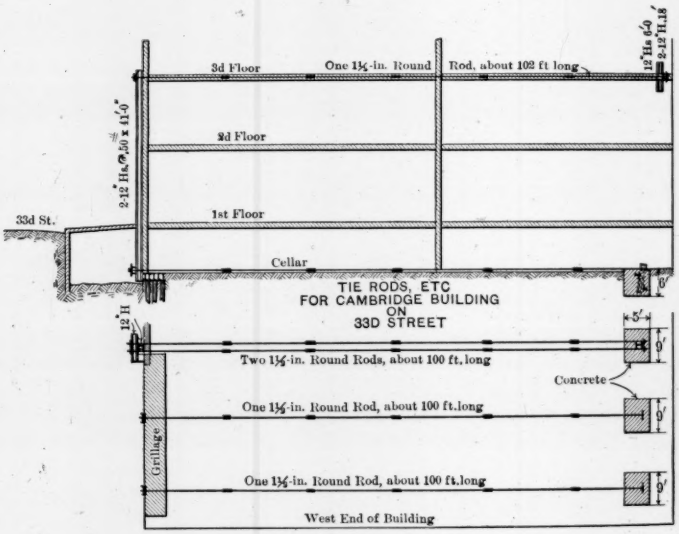



FIG. 2.

long, were set vertically, and formed seats for the two 12-in. beams (18 ft. long) to which the rod was anchored. The north end of the rod was placed just under the floor in a private office, and through the main hall.

The bottom ends of these long beams were anchored with two 1½-in. rods, just above the cellar floor. These rods were about 100 ft. long, and were made up of short sections, the rear or south ends being anchored to 5 by 9-ft. blocks of concrete, about 6 ft. deep, placed just under an old north and south partition wall, and in a position slightly

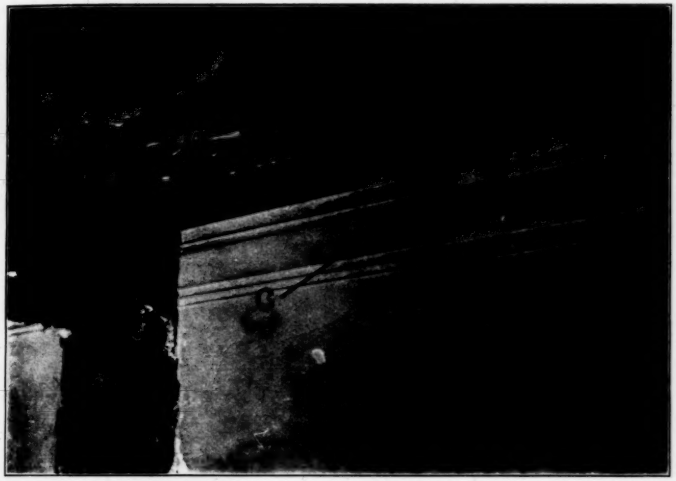


FIG. 1.—CRACKS IN WALL AND CEILING, MAIN FLOOR, CAMBRIDGE BUILDING.

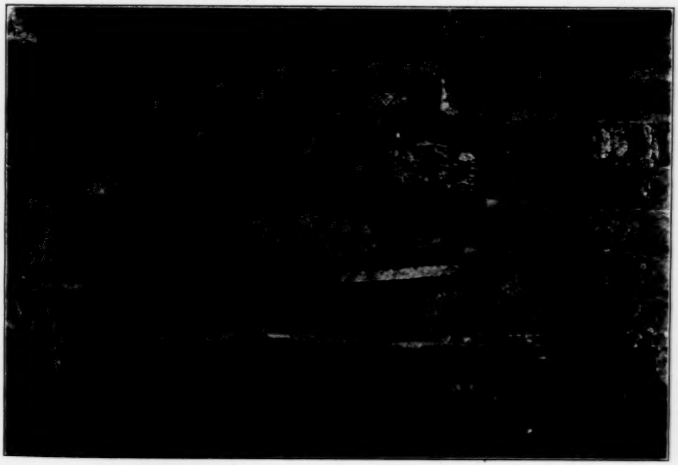


FIG. 2.—SETTLEMENT IN AREA, CAMBRIDGE BUILDING.

inclined from the vertical. Two horizontal beams were also placed in the concrete, as shown.

Near the west end of the building, another 1½-in. rod was placed, just above the cellar floor, the north end being hooked over the top of the five 20-in. I-beams, and the south end being anchored to a similar block of concrete.

Half way between this westerly rod and the first pair, a similar rod was placed and anchored in the same manner as the westerly rod.

The 41-ft. beams in front were then encased in sheet metal on account of their unsightly appearance.

The writer's examination was completed about July 23d. A contract was at once made with Mr. Alexander Brown, Jr., to tie back the building, and the work was completed in about a week.

The rods were left in place until the permanent underpinning had been completed (during the following year), and effectually prevented the north wall from pulling away, although the entire building had apparently moved north in the interval. The anchorages in the cellar, although made very heavy, showed signs of the great strain, by the cracks which opened up in the concrete floor behind them.

When the rods were first put in, in the autumn of 1907, the writer tested them to see that they were under sufficient initial strain, and when he was called in to make another report and examination, in the following spring, a similar test indicated that they were under a considerably greater strain, showing the tendency of the building to move north. In the fall of 1908, when these rods were to be removed, the men commenced to saw through the second rod from the west on the cellar floor, quite near the end attached to the 20-in. I-beams, without first slacking up the turnbuckles. When they had sawn three-quarters through the rod, it broke with a snap, and the long end sprang back about 2 ft. The men followed their instructions with the remainder of the rods, and slackened off the turnbuckles first.

The examination of the building, in March, 1908, indicated that there had been considerable vertical movement or settlement since the previous fall. Borings then taken showed that the rock was about 20 ft. below the curb at the east end of the building and about 44 ft. at the west end. The substrata were found to be partly of made ground, and below that there was sand, gravel, clay, and silt or muck, such as found in the beds of all old New York streams—a very treacherous material to have under a building.

The borings also indicated that the old stream had been entirely diverted by the tunnel, leaving the piles dry, and making their ultimate destruction by rot certain.

In the meantime the tunnel excavation had been completed, and the permanent masonry lining built in place, and it was thought that the stream which had been flowing into the tunnel the year before would back up, when it could not get into the tunnel, and again submerge the piles. The borings, however, indicated that this was not so, but that the tunnel had in some manner effectually and permanently diverted the old stream, thus lowering the ground-water level 30 ft. or more.

Reports had been obtained from H. G. Opdycke, Assoc. M. Am. Soc. C. E., Rudolph P. Miller, M. Am. Soc. C. E., Daniel E. Moran, M. Am. Soc. C. E., and Mr. Joseph Caccavajo, and, as these were similar in nature to that made by the writer, the Gorham Company (the lessee), decided to underpin the building to rock, and a contract for doing so was made with Mr. Alexander Brown, Jr., who retained the writer as Consulting Engineer to devise a plan and carry it out.

The east end of the north wall of the Cambridge Building was occupied by the show windows of the Kirkpatrick Jewelry Store, on the Fifth Avenue and Thirty-third Street sides of which store the old brick wall in the first story had been removed and a number of 8-in. cast-iron columns had been inserted to carry the upper brick wall and floors.

This is a kind of construction very frequently resorted to in converting old buildings into stores, etc., and answers the purpose as long as the foundations are not disturbed, or the walls jacked against, as there is no transverse bracing between the columns; therefore it was decided not to use the old system, which involved jacking against the building to force cylinders or walls into the ground.

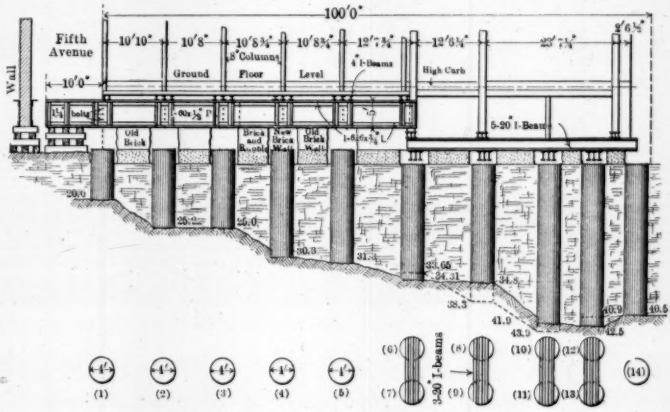
Under this end of the wall, from the curb to the cellar, there was a wall of brick and rubble masonry with some ashlar facing, which had been built, as was customary at the time and for that class of work, without any engineering supervision or advice; in other words, it was of the usual poor construction.

This foundation wall rested on a concrete footing, and on top of the wall were set the 4-in. beams, which for the length of the wall, formed a base for the 8-in. cast-iron columns.

As it was not advisable to do much cutting in this wall in the condition it was then in, it was decided to reinforce it by placing a 5-ft.

plate girder on each side about 1 ft. below the 4-in. beams, to bolt these two girders together with 1¼-in. bolts, and to grout the spaces between the girders and the wall. These spaces were usually 1 in. or more in width, as no attempt was made to dress down the surface of the masonry. As these girders in place were to be about 67 ft. long, they were each shipped in two sections in order that they might be put in position readily.

The west end, shown by Fig. 3, rested on the end of the old 20-in. steel beams, and the south end on a timber blocking under the sidewalk of Fifth Avenue.




METHOD OF UNDERPINNING THE CAMBRIDGE BUILDING

FIG. 3.

These girders had ½-in. web plates and one 6 by 6 by ⅜-in. angle in each flange.

After the underpinning was completed, the 10 ft. under Fifth Avenue was sawn off, and a space of about 4 ft. was cut out for a door just west of the splice, the splice having been placed at that point on account of the door.

The girders were placed a little more than 2 ft. 2 in. apart, back to back, and, with the exception of the south end and the space cut out for the door, were eventually bricked up on both sides, making a solid wall on top of the cylinders. As soon as the cylinders were in place and grouted, three 9-in. beams were placed under the 4-in. beams and under each column. The ends of these 9-in. beams were wedged up on

top of the 5-ft. girders, thus transferring the load from the columns directly to these girders. The holes around these short beams were then filled with concrete and brickwork. There were six 8-in. cast-iron columns resting on this pair of girders, and it was now considered safe to undermine two columns at a time in order to make room for the underpinning cylinders, one of which was put directly under each of the five most easterly columns.

As the sixth column and the remainder of the wall, or the portion from the east side of the entrance to the west end of the building, was being carried on the five 20-in. grillage beams, resting on the concrete-capped piles, it was thought that it would be too expensive and dangerous to try to put the cylinders directly under the columns, especially as it would have been necessary to cut out the old piles all the way down. Therefore it was decided to sink four pairs of cylinders, as close to the grillage beams as possible, and then remove enough concrete to place 20-in. I-beams under the old grillage beams, the ends of these short beams to rest on the pair of cylinders, and wedges to be driven between the short beams and old long grillage beams. Three of these short beams were inserted over each pair of cylinders. At the extreme end an additional cylinder was sunk on the center line of the wall, making, in all, fourteen cylinders for the support of the building.

Two additional cylinders were sunk in the areaway, to support the north end of the boilers and the area wall.

Mr. Brown called for bids on this plan, and awarded the contract to Thomas B. Bryson, Assoc. M. Am. Soc. C. E., as his bid was less than half as great as the other bids, and it was concluded that he could do a good job and make a fair profit, both of which he did. He also gave a bond to the owners for twice the amount of his contract. His total contract, including the extra work, was about $13 000, which included supplying and sinking the sixteen cylinders, filling them with concrete, supplying and placing the girders and beams, doing the necessary wedging, etc., and back-filling with concrete where necessary.

The cylinders (Fig. 4) were 4 ft. in diameter, and had very thin shells. The method of placing them constitutes a new system of underpinning; for, instead of placing the bottom section first and jacking it into the ground, and then placing another section on top and repeating the operation, a space was excavated for the top section, which was made 4 ft. deep, and the space outside of this top section was back-

filled, generally with concrete, and remained permanently in that position.

A laborer then entered the top section and, with a short-handled shovel, excavated the material under the "cutting edge" sufficiently to insert one segment of the next ring. All the rings below the top

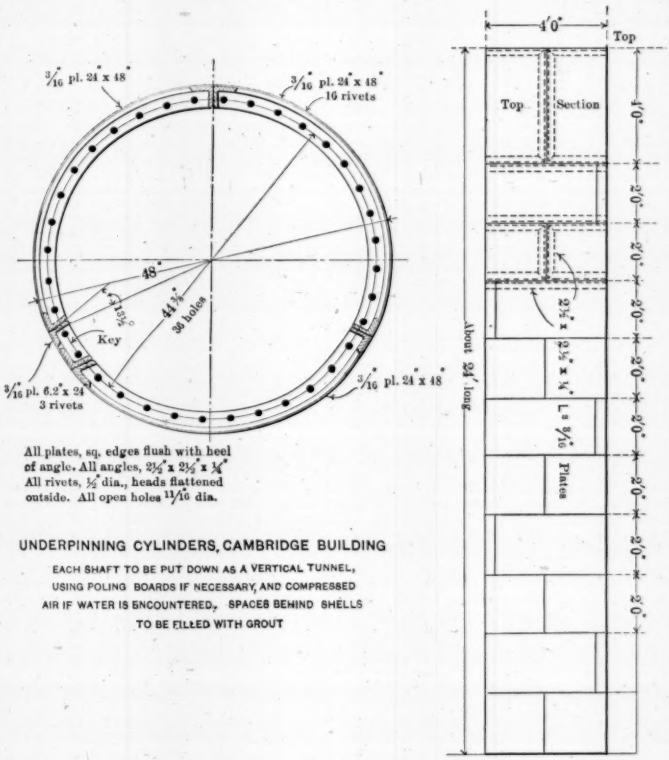



FIG. 4.

section were 2 ft. deep and in four segments, one of which was small, to act as a key, as in tunnel lining. In this key segment the connection angles were bent 13½° from the radial, to permit putting the key in place. The joints of the other segments, of course, were on the radial lines. All the plates were $\frac{3}{16}$ in. thick, and all the angles (horizontal

and vertical) were 2½ by 2½ by ¼ in. When the first segment under the top section had been bolted in place, the excavation was made for the second segment, then the third, and then the fourth or key. Where the ground was good, the excavation was made for all four segments at once.

Although the borings showed that all the water had been drained off, it was considered desirable to provide in the contract for doing the work under compressed air if water should be encountered, and the first cylinder to be sunk had gaskets in the joints; but, as it was found that the borings had been correct in showing the absence of water, no effort was made to obtain water-tight joints in the other fifteen cylinders.

In sinking one of the cylinders the rock gave evidence of having been blasted, as it undoubtedly had been, as this cylinder was directly over the tunnel. The flushing of the street near the Waldorf allowed considerable water to percolate and get into the uncaulked joints of the cylinder, sometimes in quite a stream, but it was noted with surprise that this water disappeared as soon as it reached the bottom of the cylinder, passing into the drains or crevices alongside of the completed tunnel, although these drains were supposed to have been blocked off or choked up.

This proved the existence of the second danger feared for the Cambridge Building, resulting from the construction of the tunnel. The first was the rotting of the piles due to the removal of the ground-water, and the second the removal of the subsoil, especially where it was muck or silt, as in this case, by the continual draining of the water from the streets, old streams, etc., into or alongside of the tunnels, for it is known, of course, that such continual drainage must carry a large amount of soil or muck with it, causing a gradually enlarged cavity which, sooner or later, would be filled from above, perhaps suddenly, and with disastrous results.

This action is occurring in so many places in New York City that some day we may expect to see a whole building suddenly collapse, like some of the villages in mining districts.

These plans were drawn up in July, 1908; Mr. Bryson was awarded the contract early in August, and by August 21st he had the first cylinder on rock, having spent 4 or 5 days on it, as his men were new to the work, and extra precautions were taken against water, etc. The other

cylinders were put down at the rate of about 2 days each for a depth of about 30 ft. below the curb, the sixteenth or last cylinder being completed exactly 30 days after the first was landed. Generally, an attempt was made to work on two cylinders at a time, but in such cramped spaces it was difficult and subject to delays. Mr. Bryson sublet the placing of the four 33½-ft. girders to Mr. Frank M. Tench, who handled the ticklish problem without disturbing the sidewalk in front of the jewelry store. As the cellar under this store was a salesroom for valuable goods, such as statues, paintings, etc., it was necessary to build a tight wooden partition, about 5 ft. south of the wall which was reinforced by the girders, before work was started, and, after the girders had been bricked in, furred and plastered, the rich red burlap was replaced before the temporary partition was removed.

In order to get permission from the tenants, Mr. Brown had agreed to restore the premises of the Kirkpatrick Company by the end of September, on account of the fall trade, and, by working day and night, he succeeded in doing this.

Table 1 shows the order in which the cylinders were sunk, their depths, etc.

TABLE 1.

| Order of sinking. | No. on plan. | Date of reaching rock. | Depth of rock below curb, in feet. |
|---|---|---|---|
| 1 | 11 | Aug. 21-08 | 41.9 |
| 2 | 10 | " 26-08 | 43.9 |
| 3 | 8 | " 29-08 | 38.3 |
| 4 | 9 | " 31-08 | 34.8 |
| 5 | 13 | Sept. 5-08 | 42.5 |
| 6 | 12 | " 7-08 | 40.9 |
| 7 | 4 | " 8-08 | 30.3 |
| 8 | 2 | " 9-08 | 25.2 |
| 9 | 5 | " 11-08 | 31.3 |
| 10 | 3 | " 12-08 | 25.01 |
| 11 | 1 | " 14-08 | 30.0 |
| 12 | 7 | " 14-08 | 34.3 |
| 13 | 6 | " 16-08 | 33.6 |
| 14 | 14 | " 17-08 | 40.5 |
| 15 | 15 | " 18-08 | 41.4 |
| 16 | 16 | " 21-08 | 36.0 |

It might be stated here that although there was continual settlement up to the time that this building was underpinned, there has been absolutely none since. At one time, when the building was being tied back, the settlement of the area wall broke a 4-in. water main, which caused a good deal of worry, as the water started to flow around the

boilers, and soon would have found its way into the tunnel. It took 3 hours for the proper authorities to cut off this pipe. However, as soon as the pipe broke, the men made a dam of sand bags, thus keeping most of the water away from the low spot around the boilers and allowing it to escape into the sewer.

The writer wishes to thank those connected with this underpinning work, namely, Mr. John S. Holbrook, Vice-President of the Gorham Company; Henry G. Opdycke, Assoc. M. Am. Soc. C. E., Consulting Engineer; Mr. Alex. Brown, Jr., General Contractor; Mr. Frank M. Tench, Erecting Contractor; the Cockburn Barrow and Machine Company, which supplied the steel cylinders, and Lewis F. Shoemaker and Company, which supplied the steel girders, for the way in which each did his share in stopping the settlement of this building.

# DISCUSSION

Mr. Opdycke.

HENRY GORTON OPDYCKE, ASSOC. M. AM. SOC. C. E.—In connection with Mr. Thomson's paper the speaker simply desires to emphasize a point or two therein, and to call attention to the necessity of engaging competent engineers by owners of property adjoining operations of the character of this tunnel, before such operations have commenced. There are several reasons for this, the first of which is, that, by reason of the individual's more intimate knowledge of the conditions obtaining at his particular location, he is better able to forestall operations which will endanger his property, and it is important for the owner to lay the foundations for proper legal measures to recompense him for his possible damage; also, by consultation with the contractor's engineers, operations which may endanger his property may be prevented.

In the case in point, as far back as several weeks before the cave-in on Thirty-third Street opposite the Cambridge, the speaker notified the owner of the property of the impending danger. The owner did not appreciate the dangerous condition, however, until several weeks later, after the street had caved in at the very point designated as the bed of the old stream, although the contractor had placed much dependence on the location of this stream as shown on the Vielé map, which indicated that it was about 100 ft. farther west.

In the speaker's reports to the owner, before the cave-in, it was recommended that the tunnel company be requested to lower the grade of the tunnel in order to escape this serious condition, but this was not acted on, and, after the cave-in, when the contractors asked for consent to continue their operations, this owner was in position to know his status and to require a contract, not only guaranteeing the integrity of his building, but its actual underpinning to bed-rock.

After the consent to continue operations had been obtained from this owner, the tunnel company concluded to lower the level of the tunnel, and this was finally done.

By reason of this first cave-in, together with the effect of the misdirected blast under the foundations of the Cambridge Building, mentioned by Mr. Thomson and shown on Fig. 1, the front wall of the building commenced to settle and move northward toward the center of the street. It was then that photographs were taken for the purpose of preserving legal evidence of the facts.

The speaker may state that the conditions predicted to the owner were entirely fulfilled, and the lessee of the building, who, under his lease, was responsible to the owner, was enabled to recover a judgment in the Supreme Court for the full amount of his damage, together with the court costs.

Mr. Opdycke. The speaker desires to emphasize another phase of the situation at the Cambridge Building, and that is the likelihood that such structures as this tunnel will reduce the surrounding water level and provide a new channel for the escape of the water, thus leaving buildings in the vicinity which have been erected on piles subject to much damage from decayed piles.

As to the case in point, when the cellar of the Waldorf-Astoria (on the north side of Thirty-third Street and directly opposite the Cambridge Building) was being constructed, the owner's representatives remember very distinctly the presence of much water, apparently from this old stream, and also that a sump in the boiler pit, in the basement of the Cambridge, was continually filled with water until after the openings were made into the tunnel excavation.

Borings were made in the cellar of the Cambridge after the two openings were made into the tunnel, and an examination by the speaker developed the fact that the water had been entirely drained from the soil surrounding the piles, and down to bed-rock.

When, early in 1907, the speaker examined the interior of the tunnel, water was flowing into it through the opening in the rock where the street had caved in, and after this part of the tunnel was sealed off, and the water shut out, instead of again raising the water level in the surrounding soil, the conditions mentioned above maintained, that is, there was lack of water in the soil.

There seems to be but one explanation for this condition, and that is that the water from the drainage area of this old stream still continues to flow along a new channel caused by the tunnel company's operations.

The speaker would call attention to another reason why property owners should be represented by engineers on an occasion such as this.

When the tunnel contractor saw fit to tie back the north wall of the Cambridge, he began operations by cutting a hole in the front wall of the building, in the middle of the principal office of one of the best tenants, at a point about 2½ ft. above the floor, the intention being to put a tie-rod through this office out into the main hall directly in front of the elevators, and across the main stairway, effectually obstructing them, or giving all the tenants the choice of crawling under or hurdling over the tie-rod.

This was unnecessary, as was demonstrated by the fact that tie-rods were finally put in with no permanent inconvenience to the tenants.

Mr. Yates. E. A. Yates, Assoc. M. Am. Soc. C. E.—In placing the foundations for the Assay Building, New York City, it was deemed necessary to underpin the buildings on the north side of the site to rock. Five underpinning caissons were placed, two of which were sunk by the

method described in Mr. Thomson's paper, except that compressed air was used. Mr. Yates.

The rock was about 60 ft. below the curb. There was an average depth of 8 ft. of hardpan above the rock; above the hardpan there was a mixture of sand and clay, and above this fine water-bearing sand.

The caissons were 3 ft. 6 in. in diameter. The rings were 1 ft. 6 in. in depth, and consisted of three segments and a key. A top section, 7 ft. in depth and 3 ft. 6 in. in diameter, was ditched first so that the lower portion came to the water line. The lock was then bolted on and blocked under the foundation footings.

On account of the use of air, it was necessary, in putting the rings together, to get tight joints, and therefore tar-paper was used for gaskets; a wash of neat grout was also applied, and, between the two, fairly good results were obtained. Grout holes were placed in each ring, and on the completion of every second ring the cutting edge was pugged up, and the two rings were completely grouted.

The excavation was made the full 18 in. for a complete ring, and the ring was then assembled and bolted. There was no difficulty in holding up the ground for this depth, as it stood well on being dried out by the air.

The rate of progress in sinking a caisson of this type does not depend on the rapidity of excavation, but on the speed in assembling and bolting up the rings, in making the joints tight, and in grouting. Fully nine-tenths of the time consumed in making 18 in. of progress is taken up in the latter operations, the excavation consuming the remaining tenth. If the depth of the ring was increased to more than 18 in., the speed would probably be increased, provided there was no trouble in opening up the face for so great a distance. On the other hand, if the depth of each ring was diminished to less than 18 in., the speed would be reduced but greater safety would result.

The three remaining underpinning caissons were sunk by a method in which the cutting edge was buried or followed very closely to the excavation.

A comparison of the progress of the two methods shows that the speed of the segment method is about three-fifths that of the other.

Ogden Merrill, Assoc. M. Am. Soc. C. E.—It is difficult to compare the method of sinking shafts with plates, as described by the author, with that referred to by Mr. Yates, because, with the former, it is not necessary to use compressed air and, therefore, the problems due to pressure are not encountered. Mr. Merrill.

The speaker has had occasion to note the great care which is necessary when the plate method is used under air conditions on an underpinning job in the lower end of Manhattan. The joints must be absolutely tight, and the least carelessness on the part of the men in per-

Mr. Merrill. forming their work soon becomes evident by the increased speed of the compressors. The loss of air through the joints near the upper portion of the shaft will also cause trouble by disturbing the ground.

There is also some danger in digging down for the plates, but this is not present in so marked a degree when there is no air on the shaft, because, under pressure, if the loss of air should reach an amount sufficient to lower the pressure, there would be danger from the ground coming in on the sides. This is especially the case where it is necessary to keep the pressure close to a balance with the water pressure.

Of course, the speed of putting down cylinders with the plate method becomes greater as the men become more accustomed to the work, but where it is necessary to make provision for air leakage, the progress is necessarily slower than if the work is done in the open.

On the work referred to (with the plate method) another system which seemed to work somewhat better under air conditions was used. This consisted in using a nest of telescoped cylinders or caissons. This nest was first ditched about 7 ft. in the ground, and then the inside sections were jacked from within the outer section until there was only a lap of about 3 in. This process was repeated with the remaining cylinders until the necessary depth was reached. In other words, the telescope was extended by using jacks which were operated by hydraulic pressure transmitted from a pump outside the lock. The friction was very small, because the sections were only 6 ft. long, and, therefore, there was no great amount of moving shaft in contact with the ground. The resultant upward pressure, therefore, was very small and was taken care of by the resistance against movement of the first section put in place. The friction of the section in place created a force greater than that required to jack down the succeeding sections. At all times the cutting edge was kept buried in the ground.

The method described by the author is very well adapted for special cases, and can be used where no other would be favorable, as it enables the workmen at any time to remove any particular plate, and, if necessary, to work out from the shaft proper.

Mr. Lowinson. Oscar Lowinson, Assoc. M. Am. Soc. C. E.—The method adopted in protecting this building shows ingenuity and skill for which the author deserves great credit. The low cost of the work is a matter of great surprise to the speaker, for compared with former methods of excavation and sheet-piling, the cost is possibly one-third of what it would have been with those methods.

In the underpinning work continually going on in New York City, by reason of the construction of subways and the carrying down of footings of adjoining buildings, such problems are at times entirely different from those which engineers formerly had to meet, and the advances in their solution show the skill with which they are met.

J. C. MEEM, M. AM. SOC. C. E.—Before discussing this interesting paper, the speaker desires to ask why box sheeting was not used in sinking the pits for the underpinning of this building? He has supervised much underpinning work of a similar nature, and has had uniformly good results with such methods where no water was encountered and where, in consequence, it was not necessary to use compressed air. Mr. Meem.

In connection with work of a similar character, it may be of interest to describe the following:

In building a section of the Bridge Loop Subway on Centre Street, adjacent to the new Metropolitan Police Headquarters, it became necessary under the original plans to underpin a portion of the building. The method devised by the contractors, the Cranford Company, for whom the speaker was Engineer, was to sink box-sheeted pits, adjacent to the footings of the building, to the level of the ground-water at mean high tide. These pits were then continued with interlocking steel sheet-piling or, in case great depth was required, hollow cylindrical piling. The sheet-piling was the interlocking, United States type in 6-in. sections, and the cylindrical piling was a telescopic hollow piling known as California stove-pipe, No. 12 gauge, and varying in diameter from 14 to 30 in.

There was no difficulty in sinking the steel piling to the shallower depths, but several difficulties presented themselves in connection with getting the cylindrical piles down to the greater depths, as they could not be jetted owing to the proximity of the piers, and it was difficult to clean them out without jetting, as well as to get a reaction for the jacks where necessary for driving.

The character of the material covered the widest range, being so soft under one end of the building as to render the cleaning out of the piles hazardous, while under the other end the sand, gravel, and large cobble-stones were so compacted as to make it virtually impossible to sink the piles without excavating ahead. Resort was had eventually to large cylinders, 30 in. in diameter.

These permitted a man to work inside with a long bar and with scoops, but, as it was dangerous to pump, not much gain was made due to this increase in size. In one case a diver was sent down to dislodge the larger cobble-stones, but he met with only fair success. At the time of the consummation of the change in plans for the adjacent subways, which rendered unnecessary any further underpinning at this site, the contractors were considering two methods of operation. One was the use of air in the cylinders, the other was the use of large cantilevers carrying one set of piers and reacting against those in the rear. The building being long and narrow was very well adapted to such a method. These cantilevers would have been borne on a central pier longitudinal with the building and sufficiently far back

Mr. Meem. to have its footings outside the zone of danger from the subway excavation.

This cantilever method was subsequently adopted for the building on the northeast corner of Centre and Hester Streets, its narrowness (only 9 ft. over all) making this method especially applicable. Box-sheeted pits were first sunk to water level, and from this level cylindrical pits were sunk to the required depth, cleaned out, and filled with concrete. On these piers the cantilever beams were erected, supporting the front piers and reacting against the rear wall.

This method of operation gave satisfactory results, from every standpoint.

Mr. Thomson. T. KENNARD THOMSON, M. AM. SOC. C. E. (by letter).—The maps in Mr. Opdycke's office are much more accurate than the old Vielé map, and are very valuable in showing the location of all the old ponds and streams in New York City.

Mr. Yates speaks of the five underpinning cylinders put down by Mr. Merrill, on the Assay Building, the first three being according to Mr. Merrill's patent for telescopic cylinders, and the last two by the method described in this paper.

In the telescope method the depth everywhere is only 30 ft., the diameter of the top section is, at least, from 6 to 8 in. greater than that of the bottom section, and, of course, this difference would increase with the depth. Even at these depths there was more or less trouble and delay in jacking the sections down.

As already stated, there was no difficulty in this case in going 18 in. below the cutting edge, in fact, the writer would have been willing to use 2-ft. vertical sections instead of 1½-ft. sections, for it is very seldom that the caisson excavation is not carried from 1 to 2 ft. below the cutting edge before sinking, without any trouble resulting.

Mr. Yates states that there was some trouble in getting an air-tight job, which is not surprising, as nearly all the segments had uncaulked holes, of at least ¼ in., between the plates and angles, which were not adequately plugged on the first cylinder sunk, but these gave no trouble on the second cylinder.

When working on the Cambridge Building, the men required about 4 days to sink the first cylinder, but, when they became accustomed to the work, the time was decreased to about 1½ days.

Mr. Merrill considers it a risk to undermine the cutting edge for fear of a cave-in if anything happens to the air supply; experience has shown that the material in lower New York City will safely stand that amount of undermining, as testified by Mr. Yates in the work on the Assay Building, under air pressure. Of course, if the air pipe broke, the material would rush in at once, and the fact that the excavation was 2 ft. below the cutting edge would make very little difference,

for the sand would be forced far up into the cylinder. For instance, in a recent accident, in the heart of New York City, the pipe supplying air to a caisson, 13½ ft. square, suddenly broke and within 15 min. the sand filled the air-chamber and the shaft for 10 ft. above the deck, or 16 ft. above the cutting edge, and the water rose 42 ft. in the shaft. Fortunately, there was no high building near. One gang of men had just come out, and another had started down the ladder. The water rose as fast as they could climb. Mr. Thomson.

Mr. Meem asks why box-sheeting was not used. In the first place, it would take up too much room in a small shaft; in the second, it would be more difficult to make it air-tight, and, besides, it was necessary to have the steel shell to strengthen the shaft so that the full load could be put on almost at once, without waiting for the concrete to gain its full strength. Therefore, under these circumstances, the steel was the cheaper, quicker, and safer.

Cylinders too small to allow a man to work in (less than 30 in. in diameter) have been tried repeatedly and have given unsatisfactory results. If the cylinders are carried below the water level in lower New York City, it is absolutely necessary to use compressed air. The method of forcing cylinders down by the aid of a water-jet has also been tried several times in New York, with very unfortunate results, to say the least.

Mr. Lowinson refers to the economy of this work, and his remarks are appreciated, because he has had a great deal of experience in every branch of building construction.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1149

# THE EFFECT OF ALKALI ON CONCRETE.*

By George Gray Anderson, M. Am. Soc. C. E.

With Discussion by Messrs. R. A. Hart, Rudolph Hering, Richard L. Humphrey, George F. Morse, Richard H. Gaines, Thomas H. Means, F. E. Robertson, Philo H. Bates, E. P. Goodrich, W. E. Belknap, and George Gray Anderson.

To some extent, this paper is a continuation of the informal discussion on "Irrigation" which took place at the Annual Convention of the Society, held in Denver, Colo., in June, 1908.†

In that discussion some reference was made to the introduction of more permanent structures in irrigation work; that, for such, concrete was being used extensively; and that, in some smaller structures, failures had occurred, in the form of crumbling or disintegration, due, presumably, to the action of the alkali frequently present both in the soil and in the water, and resulting from chemical reactions between the sulphates in these waters and the cement, which reactions may not yet be fully understood and are under investigation. Since that time the subject has received more than passing attention from the Profession and the industry at large, as shown by more or less extended comments in the technical and trade journals.

Several instances of such failures were referred to by members who took part in that discussion, and it is largely the purpose of this paper to consider these and other instances somewhat more fully, to elicit further discussion and consideration, and, if possible, to arrive at more

* Presented at the meeting of February 16th, 1910.
† *Transactions*, Am. Soc. C. E., Vol. LXII, p. 1.

definite conclusions in reference to the disintegrating action of alkali, in the soil and in the water, and of the methods of counteracting it.

It should be stated, at the very outset, that the subject is not approached with alarm, but rather with an inquiring mind.

Irrigation development has passed the stage in which temporary structures are considered; and the Engineer is looking for permanence, from the economic standpoint of reduction in cost of maintenance, operation, and renewals. He is almost ready to consider favorably the use of concrete, in all forms and for nearly all structures. Under observation, certain defects, arising from natural conditions which are almost always present in the regions of operation, have become apparent; and these cause a temporary hesitation and further consideration of plans and methods. The attitude is by no means that of abandonment, but rather of painstaking investigation of all the conditions, with the desire to ascertain the cause, and, from that, to introduce methods which will overcome the defect. Most certainly it is not the desire to magnify unduly the significance of a few isolated instances of failure, or to ignore defective constructional methods in these, but rather to investigate methodically all phases of the failed structures. Such investigation is now being made by the chemical branch of the Reclamation Service, as well as by others, and until official reports are published, such discussions as the present may be considered premature. In view, however, of the great amount of work under way and in contemplation in regions known to be affected, and the serious importance of these matters, not only to irrigation engineers, but to all members of the Profession engaged in structural work using concrete in contact with alkali (in soil or in water), it is not out of place to add the available knowledge and information to the more extended and methodical inquiries.

It is well known, of course, that alkali is present in greater or less amount in the soil of the arid regions. In the disintegration of the rocks, the minerals have been broken down into mineral salts which have remained in the soil as soluble salts. The rainfall and the drainage of the region are insufficient to carry these salts out of the soil through the subsoils and eventually into the streams and rivers, as is the case in the more humid regions.

The accumulation explains the wonderful fertility of the soil in arid regions, and at the same time accounts for the menace to the purely

agricultural interests. In sandy soils, with free drainage, irrigation assists in the removal of these salts; in the closer soils, such as shale, with less drainage, it may and does increase the accumulation to a harmful degree.

All are familiar with the results in connection with agricultural operations. Efflorescence in large amounts is a sure indication of alkali, and then it is in its least harmful form. What is known as "black alkali" is much more injurious to plant life. The latter form represents the alkaline carbonates, which actually dissolve the organic materials of the soil, and kill the germinating seeds or roots of the plants; the former, the white alkalis (of which the most common are sodium sulphate, sodium chloride, magnesium sulphate, and magnesium chloride), are not in themselves poisonous to plants, nor do they attack the substance of the plant roots; but they are injurious when in excessive amounts, as they prevent the plants from taking up their needed food and water supply.

It has been tolerably well determined just what amount of soluble salts is limiting for plant growth, varying with the character of the salts, of the soils, and of the plant itself; for crops differ in their ability, and some will thrive on soils on which others would languish.

Such, very briefly, is the general action of "alkali" on agricultural interests. The salts are largely the sulphates of lime, magnesia, soda, alumina, iron, and potash, and the carbonates of soda and potash. Of these, the sulphates only may prove injurious to concrete, and as the shales of the Dakota formation are known to be rich in alkalis, and are common throughout the arid regions, the effect of these soils and their salts on concrete structures will be set out by brief reference to a few known cases where this action has taken place.

A good many, if not all, of the projects of the Reclamation Service are located in alkali regions, and, thus far, the attention of the engineers has been directed to the failure of concrete structures on only two of these projects—one in Montana and one in Wyoming.

These failures may indicate some special peculiarity of the local soil, and may be somewhat similar to the well-known fact that the action of sea water has been destructive to concrete in certain localities and not in others.

The Service has started an investigation, which is still continuing, and the chemist's report has not yet been published, but Mr. Jewett,

the cement expert of the Service, in a paper before the American Society for Testing Materials, set forth some of the conditions, as will be shown by the following extracts*:

"On the Sun River project * * * its effect has been seen in the disintegration of a number of small structures, such as pipe culverts, which are partially submerged in the small streams carrying the drainage of the surrounding country. The effect of this water in causing the disintegration of the concrete is noticed, both in the softening of the material where constantly submerged for a period of three or four months, and also more particularly in the breaking up of the structure at the line where the water rises and falls, or, in other words, where there is a submersion followed by a drying out, followed by another submersion, etc. This process brings about a breaking up of the structure, similar in appearance to that of the effect of freezing, only much more severe. It is described by the engineer in charge of this work as follows:

"'On examination of some of the concrete culverts which have been in place in alkali water for three or four months, the part under water is much softer than the part above water, but the greatest effect of the alkali seems to be at the water surface. Have examined pieces of these culverts taken from below water level and found, by microscopic examination, minute crystals which disintegrate on being exposed to the air and become a fine powder. This process of crystallization has an enormous expansive force, the same as freezing, and this undoubtedly has an enormous disintegrating effect. One culvert which had been in alkali water several months had no strength at all and was like so much sand and mud at the water level.'

* * * * * * *

"In studying the cause of this disintegration it seemed that a chemical analysis of the water producing these results would be the first step of importance to be taken. The results obtained from an analysis of this water are as follows:

| | "Milligrams per Liter. |
|---|---|
| "Calcium sulphate ($Ca\ SO_4$) | 1 690 |
| Magnesium sulphate ($Mg\ SO_4$) | 6 870 |
| Basic magnesium carbonate ($MgH_2\ CO_2$) | 305 |
| Magnesium chloride ($Mg\ Cl_2$) | 192 |
| Potassium chloride ($K\ Cl$) | 20 |
| Total solids | 9 077 |
| Weight after ignition | 8 855 |
| Loss on ignition | 222 |

* *Proceedings*, Am. Soc. for Testing Materials, Vol. VIII, 1908.

"From this analysis it will be seen that the principal mineral ingredient of this water is magnesium sulphate, and this leads to the conclusion that the effect of this water in causing disintegration of concrete is similar in its action to that of sea water in which magnesium sulphate is stated to be the principal substance acting to bring about the disintegration of concrete with which it comes in contact."

Professor Headden, of the Colorado State Agricultural College, has at various times issued bulletins in reference to alkali in the soil and in the water, and has recently added to his publications Bulletin No. 132 on "The Destruction of Concrete by Alkali," in the course of which he gives an account of his investigation of cement tiling which had rapidly deteriorated. From that bulletin the following is quoted in order to convey clearly the conditions:

"The following case of deterioration may be of some interest as it presents some new points. There were sent to me some months ago a number of fragments of tiling which had been laid but from eight to nine months. They had been disintegrated to such an extent that one of the samples was simply a white putty-like mass mixed with sand. There was nothing about this sample remotely suggestive of concrete. Another of the samples consisted of a fragment of the tile, the interior portions of which had been wholly decomposed, while there still remained an outer and inner portion in good condition, or comparatively so. Another sample had been attacked on the inner side leaving the mass of the tile outside of the zone of decomposition apparently sound. The line of decomposition was sharply limited and showed distinctly, but even in this case there remained a thin layer of cement on the inside.

"I do not know whether the tile were running full of water or not, probably not, as the fragments seem to be parts of 16 or 18 inch tile. The importance of this point is simply this, that it would answer any question in regard to the separation of solid 'alkali' salts on that portion of the tile above the water line. That such a separation of these salts should take place does not seem very probable in this case.

"The point of attack, so far as the samples at my disposal indicate, is either in the center of the cement mass or near the inner surface. In either case we are almost compelled to assume the action of the water, i. e., of the salts held in solution. At the same time we see the resisting power of the outside and inside surfaces, which are evidently richer in cement than the inner portion of the mass of the tile.

"The sand used in making the tile was quite fine. The proportion used was 5:1. We can readily see that the individual masses of cement in the interior mass of the tile must be small and readily attacked by solutions of salts capable of reacting with the cement.

"It seems quite evident that the agents causing this disintegration of the cement must gain access to the interior portion of the mass of the tile in the form of a solution, but it is a question whether this solution is the same in strength and character as the water in the drain. I think that I have clearly shown in Bulletin 65 of the Colorado Experiment Station, page 34, that the water soluble portion of the soil is different from the salts held in solution in the ground water. Further, in Bulletin 72, page 28 *et seq.*, that the ground waters are different from the drain waters, and the action of these waters on the tile would vary somewhat according to the source of the solution which penetrated the mass of the tile.

"The drain waters obtained, say at a depth of four feet, contain as a rule a smaller amount of salts in solution than the ground water. The salts present are the same, but their relative quantities vary. The usual salts present in the ground waters are, sodic sulfate, calcic sulfate, magnesic sulfate, sodic carbonate, and sodic, in some instances also magnesic chlorid. In the drain waters we have the same salts, but their relative quantities are different, the most notable feature being the relatively large amount of sodic carbonate.

"The substances claimed to be the most active in effecting the disintegration of cement are the sulfates. In the case of sea water the explanation offered is that the lime of the cement decomposes the magnesic salts present in the water, whereby the lime goes into solution and the magnesia is deposited in its stead, causing a bulging and disintegration of the work owing to its greater bulk. The principal magnesian salt in sea water is the chlorid, the deleterious action of which on cement is not established, but it has been shown that magnesic sulfate acts energetically. The most active agent in decomposing concrete is the sulfuric acid of the sulfates carried in solution. Again solutions of gypsum have been shown to act detrimentally on concrete by forming with the tri-calcic aluminate a sulfo-aluminate.

"The water acting on these tiles, whether it be ground water or drain water, is very bad. One of the two small samples sent to me contained 1 252.6 grains per imperial gallon, of which 493.5 grains were sulfuric acid ($SO_3$) with an extremely large proportion of magnesia. The other contained 542.3 grains per imperial gallon, with 42.31 grains of magnesic oxid or 7.8 per cent. of the total solids. I have examined a number of waters from this section, and find the ground water uniformly heavily laden with the sulfates of lime and soda, with comparatively large quantities of magnesia, especially if the water comes from near the surface, as it necessarily must in the case of drain waters. In addition to the above constituents, there is uniformly some carbonate present, which for the present purpose we may consider as sodic carbonate.

"We have then an ample supply of these substances present which

are known to act deleteriously upon cement, i. e., the sulfates, a portion of which is magnesic sulfate, and in addition there is so much sodic carbonate present that its action cannot be neglected."

Professor Headden, assuming that the cement used in the tiling was an average Portland cement, with not more than 2% of calcic sulphate, then considers the action of the waters on the tile.

The white decomposition product indicated the presence of a large quantity of water, also of considerable quantities of sulphuric and carbonic acids.

The decomposed mass was washed with distilled water, and the wash-water showed that it had taken sulphuric acid, lime, and soda into solution.

An analysis of the Arkansas River water at Rocky Ford, which, Professor Headden remarks, is essentially a return water, is given, and the assumption is made that the composition of the water acting on the decomposed tiling was much the same, as are all waters in that district, varying in amounts of mineral matter, or total solids held in solution, as shown by the two samples of drain water accompanying the tiling—one having 1 252.6 grains, the other 542.3 grains.

The action on the tiling seems to be similar in Colorado and Montana. A comparison of the features of construction may not be possible.

In the Montana case, Mr. Jewett says:

"Of course, in this case, as in any other case of concrete failure, the question of poor workmanship is one of the first to be considered and it should be noted that the work in question was carried on by force account under direct supervision of employees of the Service and not by contract, and was done in the usual thorough and substantial manner, in which all of the construction work of the Service is carried on. After taking all the evidence into account there seemed to be no other conclusion but that the action of the alkali water was directly responsible for the results noticed."

Professor Headden has not much information on the quality of the tiling examined by him. The sand used was quite fine, the proportion 5 to 1, and the individual masses of cement in the interior must have been small and readily attacked by solutions of salts capable of reacting with the cement.

Both Mr. Jewett and Professor Headden find the decomposing action, in the cases of these tilings, to be similar to that of sea water,

in which magnesic sulphate is stated to be the principal agent. Professor Headden says, as already quoted,

"The principal magnesian salt in sea water is the chlorid, the deleterious action of which on cement is not established, but it has been shown that magnesic sulfate acts energetically."

Reference to this similarity to the action of sea water will be made later; meantime, the following is a summary of Professor Headden's conclusions.

The analysis may be interpreted as indicating that the cement had been deprived of silicic acid and of a relatively large amount of lime. The amounts of the ferric and aluminic oxides have been reduced to about one-half as much in the decomposed cement as in the original. The sodic sulphate, more particularly the calcic and magnesic sulphates which are present in the ground-water, will at the same time act on the tri-calcic aluminate, forming the sulpho-aluminate, which crystallizes with 60 molecules of water and is soluble. The increase of sulphuric acid (more than 20%), and also of carbonic acid (more than 12%), in the water-free decomposition product is noted, as compared with only about 1% each in the original product, while magnesic sulphate has also contributed to the result, being more than four times greater in the decomposed product than in the original; and there is the conclusion that:

"The action of the ground waters seems to have been one of chemical change, converting the lime of the cement into a sulfate and carbonate accompanied by the removal of silicic acid, alumina, and lime, and totally destroying the cohesiveness of the concrete."

The case of the sewers at Great Falls, Mont., has been referred to frequently, and is probably the most striking illustration of deterioration yet considered. The City Engineer, Mr. C. W. Swearingen, was so impressed by the conditions that he requested the authorities at the Montana State Agricultural College to investigate and report on it.

The preliminary conclusions of Mr. E. T. Tannatt, Rural Engineer, and Mr. Edmund Burke, Chemist, are embodied in Bulletin No. 69 of the Montana Experiment Station, from which the following extracts give a very clear exposition of the conditions:

"The Third Street main sewer was constructed in the year 1890, the material used being Portland cement pipe of home manufacture, made in moulds and put in place after the cement had hardened.

Sewer is oval in shape, dimensions 26 x 32 inches. This sewer, after a comparatively short term of service, showed defects of so serious a character as to necessitate rebuilding portions of the same. The remaining portion of this sewer has disintegrated in many places and occasionally portions of the pipe are gone, the cement in places has the appearance and consistency of fresh lime mortar.

"The Sixth Street main was constructed in the year 1892, the material being the best grade of common brick of home manufacture. Sewer is circular in form, four feet inside diameter, two rings of brick laid on edge in imported Portland cement mortar, outside plaster coat one-half inch thick, not plastered on inside; all cement mortar one part cement and three parts sand. The masonry in the invert in this sewer is disintegrating throughout its entire length, the defects being confined almost entirely to the invert and lower sections of the manholes; the arch is in apparent good condition.

"There is no sub-drain under, nor on the sides of the sewer. As stated before, the disintegration in the Third Street main, where cement pipe was used, commenced soon after its construction, whereas the Sixth Street main gave no evidences of defect for about seven years after its construction, and it is only during the past four years that decomposition has been rapid."

The examiners found: (*a*) that the disintegration and destructive action of the cement did not come from adulteration, nor from the quality of the materials used; (*b*) that though a limited chemical or physical action of the alkali salts may be a partial cause of the breaking down of the brick, yet the principal cause was the fact that the bricks were too soft, and not fit for sewer construction; and (*c*) that the action on the cement was chemical, that the destructive agent came from the outside of the sewer, and that the disintegration of the cement cannot be charged to any action of the sewage or gases from the same.

They found that certain portions of the sewers showed the presence of external moisture to a more marked degree than other sections, and that, contiguous to it, were various depressions in which water collected and gradually seeped into the soil, thereby affording means for the leaching out of the alkali from the gumbo, through the sand and other more permeable formations, into the back-filling adjoining the sewer, there depositing against the structure. The soil samples showing the highest percentages of alkali were taken immediately at the back of the cylinder of the sewer.

Soil samples were analyzed in order to ascertain the amount of alkali salts, whether these were being leached out and lodged against

the sewer, and the amounts at various depths, but there is no chemical investigation of the action on the cement and its alteration, which it is understood will form the subject of a later bulletin.

The analyses embodied in the report, however, show that the maximum disintegration of the sewer occurred where the greatest percentage of alkali showed in the soil, and that the ground-waters were leaching the alkali from the soils and depositing the salts along the sewer.

Messrs. Tannatt and Burke consider that the use of cement for sewers and other structures in alkali soil is inadvisable in cases where it is not possible to drain all ground-waters from the exterior of the sewer, and they recommend that drain tile be placed in the bottom of the trench, covered with clean gravel or crushed stone, and that similar drains be placed around the barrel of the sewer to provide effective drainage of the ground-waters, in order that it will not be possible for them to come into contact with the structure itself, and, where these precautions cannot be taken, they "unhesitatingly recommend that cement pipe be not used."

The writer had some experience with a construction somewhat similar to the Great Falls sewer, and in similar, though not such aggravated, conditions, but with entirely different results.

Lake Loveland was constructed under the writer's supervision in 1894. The outlet is a tunnel about ¾ mile long, nearly all of which is in stratified shale. The rock was of such a character that it would have decomposed under the action of passing waters at a high velocity, and therefore the tunnel was lined. The interior diameter of the tube was 5 ft. The invert was built of two rings of well-burned brick, and the arch was of concrete.

In the excavation, large volumes of water were developed, ultimately giving a flow of about 2 cu. ft. per sec. The water, undoubtedly, was impregnated heavily with alkali, but the writer did not obtain a chemical analysis of it, as, at that time, he did not suspect that any deleterious action might be caused by the character of the water itself; but, apart from the fact that it was "return water"—the drainage of a large section of irrigated country lying west of the reservoir—there were constant physical evidences that it contained salts, if one might judge from the action on the human system caused by drinking it in moderate quantities.

Through the whole length of the tunnel a sub-drain was channeled out in the rock bottom, and wooden boxes were placed to convey these waters. Side-drains were also placed at frequent intervals throughout the whole length, and mostly where the volume was largest, always connected with the under-drains. These were carried up as high as the drainage showed, usually to the spring of the arch. In short, every precaution was taken to prevent the water from coming in contact with the concrete, certainly until it had set thoroughly, and solely for the purpose of securing good results and without thought of any ultimate chemical reaction.

The work was done practically by force account. The materials were supplied, the labor was done under contract, and the work was in charge of a competent concrete worker and under a thoroughly able inspector.

As far as the writer knows, the concrete and the cement mortar in the brickwork are in thoroughly good condition to-day. It is nearly 8 years since he examined the work, and then it was found to be without any apparent defect. The superintendent informed the writer, recently, that he had not been in the tunnel for 2 years, but had then found it in perfect condition, and was of the opinion that it still is so.

One other structure may be mentioned, a reservoir spillway in the Arkansas Valley, or the Bob Creek Reservoir, constructed and owned by Mr. W. C. Bradbury. The writer's attention was attracted to it in September, 1909, when passing near it, on other business. He first noticed and examined a small division head-gate about ½ mile below the reservoir. It was stated, that these works had been built less than 2 years before that time. The writer had no means of knowing the proportions used in the work, but this head-gate seemed to have been fairly well built, and its upper portion was in fair condition. The floor had evidently been about 6 in. in thickness, but it was entirely decomposed, and could be crushed readily in the hand. The uprights, up to about the normal height of the water, showed disintegration. At the outlet from the reservoir, the apron was disintegrated in the same way. It had been reinforced, and the reinforcing material was exposed and bright while the concrete mass was almost completely pulverized.

The spillway to the reservoir was of considerable length and height, of ogee overfall, and had the same appearance of fairly good construction. Prior to the writer's visit, there had never been any water flow-

ing over it from the reservoir. Its lower portion, for a height of about 10 ft. above the apron level, was markedly discolored, and on breaking the surface crust, it was found that the interior mass of the concrete could easily be removed and pulverized in the hand.

About a month later, water passed over the spillway and washed out the lower section of the fall to the height already indicated. The concrete had been placed on a foundation of shale, from which the alkali water oozed. No provision had been made for the under-drainage of this water, and the conclusion is inevitable, that the destruction of the concrete was the result of the chemical action of the alkali in the water draining from the shale.

From these various instances, it would seem that somewhat new problems are presented to the constructing engineer, or, if they are not new, they are old problems under new conditions, and engineers have been prone to overlook their significance until serious consequences have forced them directly on their attention.

It is very likely true that the effects of alkali on concrete are similar to those of sea water, with some differences, as these in themselves differ in various localities. Means of overcoming the sea-water action are fairly well outlined, though as competent an authority as Feret says:

"No cement or other hydraulic product has yet been found which presents absolute security against the decomposing action of sea water."

Michaelis, on the other hand, long ago made certain recommendations which may be summarized briefly here: From the physical point of view, a dense concrete surrounded with an impermeable layer composed of 1 part of cement and 2 or 2½ parts of sand of mixed grains, of which at least one-third must be very fine, and the whole mass made, if possible, in one operation; from the chemical point of view, the use of cement rich in silica and as poor as possible in alumina and ferric oxide, and the use of substances which render the mortar, at any rate in its external layers, denser and more capable of resistance.

The solution of the problem, from the chemical point of view, will be the care of the chemists and the cement manufacturers. The problem for them is as new—or as old under new conditions—as it is for the engineer; and, conceding the general proposition that the solution lies in good construction, which the engineer must realize and will provide, there is, it would seem, the larger problem of a coating which,

adding impermeability, shall also resist the chemical reactions between the soil and water and the cement.

What is good construction under these conditions?

It seems to the writer that the engineer, under these conditions, first has to extend materially the field of his investigations before outlining plans. The character of the soil, and of the water passing over the soil and to be transported over the structure, must be thoroughly analyzed. Then, to the physical problem, similar analytic consideration must be taken of the materials used as concrete aggregates—the sand, the gravel, and the water.

On that feature, the following is quoted from Mr. Jewett's paper:

"In the case of the sand used on the Reclamation Service project above mentioned, the engineers reported that there were evidences that this sand, which was the only supply readily available, contained alkali or some substance making it chemically active and assisting in the disintegration of the concrete. A chemical analysis of this sand was therefore obtained and resulted as follows:

| | Per Cent. |
|---|---|
| "Silica ($Si\ O_2$) | 67.03 |
| Alumina ($Al_2\ O_3$) | 6.85 |
| Ferric oxide ($Fe_2\ O_3$) | 2.50 |
| Manganese oxide ($Mn\ O$) | .02 |
| Lime ($Ca\ O$) | 10.72 |
| Magnesia ($Mg\ O$) | 1.72 |
| Sulphuric anhydride ($SO_3$) | Trace. |
| Alkalis. Soda ($Na_2\ O$) | 1.74 |
| Alkalis. Potassa ($K_2\ O$) | 1.51 |
| Water at 100° C | .14 |
| Ignition loss | 8.16 |
| Total | 100.39 |

"This sand gives excellent results from physical tests but since, as will be seen from the above analysis, the alkali content is about 3 per cent. which would correspond to about 15 to 20 per cent. of feldspathic material and that it also contains a considerable percentage of limestone, it is altogether possible that this sand would be more readily acted on by the influences tending to disintegrate the concrete than a sand of a more highly silicious nature."

It is extremely likely that similar conditions will be found in most of the sands and gravels available in the arid regions where alkali is known to exist.

There is no occasion for elaboration on the care required in the selection of water for use in mixing concrete. It is quite well known that the ground- and drain-waters in most of these districts are largely impregnated with alkali; that is discernible without chemical analysis, and is particularly true in the lower reaches of irrigated valleys, where most of the waters are drain-waters, consisting of the concentrated essence of alkali from the irrigation and drainage of the upper valleys. Prior to the introduction of the gravity system at Greeley, for instance, the domestic supply from underground galleries contained as much as 1 800 parts of hardness, and, it may be added, the water used in mixing the concrete at the Loveland work referred to, was obtained, not from the drainage of the tunnel, but from the town supply withdrawn from the river inside the foot-hills.

If the action of the alkali salts in the water surrounding a concrete mass can have the destructive effect shown in the various instances quoted, it is certain that the incorporation of such water in the aggregate cannot be other than injurious.

Beyond extra care in the materials, and the production of a dense mass, there is no room to doubt the advisability of effective drainage around the structure.

Professor Headden, in Bulletin No. 72,* speaking of the alkali lands in the Poudre Valley, said:

"I am convinced that the only question of alkali that we have resolves itself into one of drainage, and beyond this, there is no alkali question for us."

It would be too much to hope that the drainage around structures would as effectively solve the difficulty of alkali in contact with concrete, but it will aid in resisting the action of the agencies at operation.

It is not possible, however, in all cases to provide such drainage as would be effective, and beyond all that—beyond the external application and the possible incorporation of an impervious coating in the mass itself—it seems to the writer that there must be added to it or in it, in some form, agencies which will counteract the effect of these apparently well-recognized chemical elements which bring destruction; and that must be left to the chemist, on whose province the writer has probably encroached too far, and, apparently, with only a speaking acquaintance with that science.

* Montana Agricultural Experiment Station.

It has been the writer's purpose to bring the subject to the attention of the members, with, perhaps, the selfish motive of eliciting discussion and enlightenment on a subject on which he is looking for light and guidance, in a continued consideration of what seems to be one of the most important subjects than can secure the attention of Western engineers, at this time. The writer is aware that there are others who are far more competent to treat this subject learnedly and practically, and will be content if his efforts have been sufficient to draw from them the knowledge and enlightenment which they possess.

# DISCUSSION

R. A. HART, ESQ.* (by letter).—The action of alkaline waters on Portland cement was brought to the writer's attention in August, 1908, by the discovery of the deterioration of some cement drain tile which had been placed in a field, in Sevier County, Utah, during February of that year. Mr. Hart.

The tile were well made and well seasoned, and in good condition when placed in the ground. Utah Portland cement was used, one part of cement being gauged with five parts of an aggregate of sand and small gravel. The tile were stored in a shed and kept damp for two months previous to laying.

After five months, the tile were in an advanced stage of decomposition, and it was possible to scrape a hole through their walls with an ordinary pocket knife; pieces of the tile could be crumbled in the hands. The material was saturated, and had the appearance and consistency of fresh lime mortar, except on the very surface, where there was a greater percentage of cement.

The water flowing from the drain was highly impregnated with the salts of various alkalis, and this fact seemed to offer a possible explanation of the deterioration. As very little information was to be had, at that time, concerning the destructive influence of alkalis, it was decided to make some laboratory experiments to determine which of the alkaline salts was doing the damage, and, if possible, to devise methods of preventing it. The chief salts of interest in drainage investigations are the chloride, carbonate, and sulphate of sodium, and it was with solutions of these that the experiments were made.

The experiments were conducted in the Mechanical Laboratory of the University of Utah, and the methods proposed by the Special Committee on Uniform Tests of Cement, of the American Society of Civil Engineers, were generally used. All the equipment was of standard type, and the best materials were used (standard Ottawa sand in the sand briquette tests).

Several series of tests were made, and each final result shows the average obtained from five separate experiments.

The first series was a determination of the setting periods of pats of neat cement gauged with solutions of the three sodium salts, chloride, carbonate, and sulphate, each in four different strengths, 0.1%, 1.0%, 5.0%, and 10.0%, and with tap-water.

Test I (shown in Table 1) shows the results of this series. Very little effect in the period of set is made by the addition of sodium chloride, except in the case of the 10.0% solution. The results, in the case of sodium carbonate, however, are very marked, both the initial

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Mr. Hart.

and final sets being delayed in those pats gauged with a 0.1% solution, while the stronger solutions cause a remarkable expedition. Special attention is called to the period of initial set of Pat 9, which was 6 min., as against 3 hours and 39 min. for the water-gauged pat. Careful examination showed that the set was genuine, and not merely a crystallized surface film. This rapid set, instead of resulting in a weakening of the cement, has the contrary effect, to a remarkable degree.

The second series is a determination of the tensional strength of neat-cement briquettes, gauged with solutions of chloride, carbonate, and sulphate of sodium, in strengths of 0.1%, 1.0%, 5.0%, and 10.0%, and with water, and then stored in water for various periods of time. The results are shown in Table 1.

Test II shows that at the end of 24 hours the presence of chloride and carbonate causes an increase in the tensional strength, which is not true of the sulphate, except in the case of the 10.0% solution.

In Tests III, IV, and V, the changes show less definition, but it seems, in general, that the water-gauged briquettes are a little stronger than those gauged with alkaline solutions, except in the case of the stronger sulphate mixtures. In one or two instances, the 1.0% solutions of chloride and carbonate give higher results.

In the third series of experiments some remarkable phenomena are encountered. This series is a determination of the tensional strength of neat cement briquettes, gauged with water, and stored in solutions of chloride, carbonate, and sulphate of sodium, in strengths of 0.1%, 1.0%, 5.0%, and 10.0%, and in water, for various periods of time. The results are shown in Table 2.

The results of Test VI indicate an increase of tensional strength, with an increase of solution strength up to 10.0%, when there is a falling off.

The same is shown in Test VII for 27 days, except in the case of the sulphates, in which the 10.0% solution gives the highest tensional strength.

Test VIII shows less uniformity of results, but the enormous strength of the briquettes stored in the stronger sulphate solutions should be noted. Some of the briquettes resisted a tension of 1 400 lb. per sq. in.

So far, no particularly harmful results had occurred from the presence of alkali, but in the fourth series, in which sand briquettes were used, the effect was marked. In this series, one part of cement was mixed with two parts of standard (Ottawa) sand and gauged with water and then stored in solutions of sodium chloride, carbonate, and sulphate. Only one test has been run in this series, which covers 28 days. The results are shown in Table 2.

Mr. Hart.

TABLE 1.—PERIODS OF SET OF PATS OF CEMENT; AND TENSIONAL STRENGTH OF VARIOUSLY GAUGED NEAT CEMENT BRIQUETTES.

| Alkali. | Percentage. | First Series. | | | | | Second Series. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Test I.—Periods of set of variously gauged pats, setting in air. | | | | | Test II.*—Tensional strength, neat cement briquettes, setting 24 hours in air under damp cloths. | | Test III.*—Tensional strength, neat cement briquettes, setting 24 hours in air, under damp cloths, then stored 6 days in water. | | Test IV.*—Tensional strength, neat cement briquettes, setting 24 hours in air, under damp cloths, then stored 27 days in water. | | Test V.*—Tensional strength, neat cement briquettes, setting 24 hours in air, under damp cloths, then stored 89 days in water. | |
| | | No. of pat. | Initial set. | | Final set. | | Sample No. | Load. | Sample No. | Load. | Sample No. | Load. | Sample No. | Load. |
| | | | Hours. | Minutes. | Hours. | Minutes. | | | | | | | | |
| Na Cl... | 0.1 | 2 | 3 | 41 | 9 | 2 | B | 312 | N | 708 | 1AA | 768 | 3AA | 729 |
| | 1.0 | 3 | 3 | 30 | 8 | 24 | C | 343 | O | 739 | 1BB | 813 | 3BB | 814 |
| | 5.0 | 4 | 3 | 31 | 8 | 46 | D | 414 | P | 883 | 1CC | 733 | 3CC | 647 |
| | 10.0 | 5 | 3 | 11 | 7 | 17 | E | 492 | Q | 741 | 1DD | 645 | 3DD | 645 |
| $Na_2CO_3$ | 0.1 | 6 | 4 | 34 | 9 | 31 | F | 283 | R | 667 | 1EE | 952 | 3EE | 751 |
| | 1.0 | 7 | 3 | 14 | 8 | 34 | G | 309 | S | 677 | 1FF | 815 | 3FF | 926 |
| | 5.0 | 8 | 0 | 9 | 1 | 22 | H | 442 | T | 728 | 1GG | 848 | 3GG | 721 |
| | 10.0 | 9 | 0 | 6 | 2 | 48 | I | 421 | U | 644 | 1HH | 717 | 3HH | 715 |
| $Na_2SO_4$. | 0.1 | 10 | 3 | 38 | 8 | 58 | J | 205 | V | 628 | 1II | 802 | 3II | 741 |
| | 1.0 | 11 | 3 | 17 | 8 | 50 | K | 235 | W | 718 | 1JJ | 822 | 3JJ | 791 |
| | 5.0 | 12 | 3 | 1 | 8 | 10 | L | 251 | X | 761 | 1KK | 923 | 3KK | 773 |
| | 10.0 | 13 | 3 | 0 | 8 | 31 | M | 328 | Y | 810 | 1LL | 890 | 3LL | 925 |
| $H_2O$.... | 100.0 | 1 | 3 | 39 | 8 | 26 | A | 241 | Z | 725 | 1MM | 867 | 3MM | 855 |

* Mean results of five experiments.

TABLE 2.—TENSIONAL STRENGTH OF NEAT CEMENT BRIQUETTES, AND OF 1:2 SAND BRIQUETTES, GAUGED WITH WATER, SET IN AIR, UNDER DAMP CLOTHS, FOR 24 HOURS, THEN STORED IN SOLUTIONS OF VARIOUS ALKALIS, OF VARIOUS DEGREES OF ALKALINITY, FOR VARIOUS LENGTHS OF TIME.

| Alkali. | Percentage. | Third Series. Neat Cement Briquettes. | | | | | | Fourth Series. 1:2 Sand Briquettes. | | Fifth Series. 1:2 Sand Briquettes. Using Water-proofed Cement. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Test VI.* Stored for 6 Days. | | Test VII.* Stored for 27 Days. | | Test VIII.* Stored for 89 Days. | | Test IX.* Stored for 27 Days. | | Test X.* Stored for 89 Days. | |
| | | Sample No. | Load. | Sample No. | Load. | Sample No. | Load. | Sample No. | Load. | Sample No. | Load. |
| Na Cl..... | 0.1 | I | 657 | 1A | 936 | 3A | 841 | 2S1 | 372 | 3W1 | 317 |
| | 1.0 | II | 682 | 1B | 979 | 3B | 861 | 2S2 | 393 | 3W2 | 389 |
| | 5.0 | III | 757 | 1C | 1 251 | 3C | 910 | 2S3 | 350 | 3W3 | 381 |
| | 10.0 | IV | 733 | 1D | 1 055 | 3D | 943 | 2S4 | 491 | 3W4 | 325 |
| $Na_2 CO_3$.. | 0.1 | V | 668 | 1E | 920 | 3E | 883 | 2S5 | 474 | 3W5 | 380 |
| | 1.0 | VI | 702 | 1F | 925 | 3F | 738 | 2S6 | 429 | 3W6 | 371 |
| | 5.0 | VII | 712 | 1G | .... | 3G | 799 | 2S7 | 423 | 3W7 | 348 |
| | 10.0 | VIII | 636 | 1H | 902 | 3H | 848 | 2S8 | 373 | 3W8 | 376 |
| $Na_2 SO_4$... | 0.1 | IX | 647 | 1I | 831 | 3I | 915 | 2S9 | 441 | 3W9 | 409 |
| | 1.0 | X | 717 | 1J | 899 | 3J | 911 | 2S10 | 380 | 3W10 | 338 |
| | 5.0 | XI | 807 | 1K | 1 064 | 3K | 1 037 | 2S11 | 206 | 3W11 | 378 |
| | 10.0 | XII | 787 | 1L | 1 108 | 3L | 1 139 | 2S12 | 58 | 3W12 | 357 |
| $H_2 O$..... | 100.0 | XIII | 697 | 1M | 867 | 3M | 838 | 2S13 | 448 | 3W13 | 414 |

* Mean results of five experiments.

Mr. Hart.

Mr. Hart.

In Test IX the results are not as uniform as in the case of neat cement briquettes, as might well be expected. They indicate, however, that there is very little weakening in the case of briquettes stored in solutions of chloride and carbonate, but that there was a remarkable weakening in the case of those stored in sulphate solutions. The tensional strengths decrease as the solution strength increases. The briquettes stored in water had a strength of 448 lb. per sq. in., those stored in a 0.1% solution of sodium sulphate, 441 lb. per sq. in., while those stored in a 10.0% solution broke at 58 lb. per sq. in. The appearance of these latter briquettes was much the same as that of the tile, and they could be crumbled in the hands.

These results, although meager, seemed to indicate that sodium sulphate was the deteriorating factor, and that its effect was on the bond between the cement and the sand. This being true, it was felt that the solution of the second part of the problem was to render the cement impervious to water. It was decided to start experiments with that end in view, before any more tests of the action of the alkalis were made.

Obviously, the mere coating of the surface of a concrete structure would not be satisfactory, as the least scratch in such a coat would render the whole structure open to destruction. The real solution lay in actually water-proofing the cement itself.

With this in view, a water-proofing mixture was secured from a St. Louis concern, and a fifth series of tests was run. It was impossible to obtain the mixture alone, but a water-proofed Eastern cement was furnished. The local cements are stronger, in general, and this fact accounts for the apparent discrepancy. In this series the water-proofed cement was mixed with standard (Ottawa) sand in a proportion of 1 to 2, and gauged with water, then stored in solutions of chloride, carbonate, and sulphate of sodium for various periods of time. Only one set of tests has been completed at the present time, the results of which are shown in Table 2.

In Test X the results are not as uniform as in the case of the neat cement briquettes, but they show pretty conclusively that there is no serious deterioration after three months.

Since these experiments were begun, Bulletin 69 of the Montana Agricultural College and Bulletin 132 of the Colorado Agricultural College, have been received. These bulletins corroborate many of the writer's observations, but approach the question from different angles.

These experiments are being continued by the writer, and are being extended to include a study of the effect of the waters of the Great Salt Lake, which contain a large percentage of alkaline salts.

The foregoing results are submitted for whatever they may be worth, and no discussion will be attempted by the writer.

Mr. Hart. Acknowledgments are due to C. G. Elliott, M. Am. Soc. C. E., Chief of Drainage Investigations, U. S. Department of Agriculture, for permission to present this information, and to Dr. William Blum, and Professor E. H. Beckstrand, of the University of Utah, and Mr. O. C. Hart, Chemist of the Utah Portland Cement Company, for valuable information and assistance.

Mr. Hering. RUDOLPH HERING, M. AM. SOC. C. E.—This paper is very timely, not only in calling prominent attention to the subject, but in giving some preliminary conclusions which appear to the speaker to be along the right lines.

The destructive effect of alkali may be traced partly to alkaline ground-waters coming in contact with a concrete structure, and partly to alkaline waters which may be conveyed in a concrete channel. In both cases, however, there is a water contact.

The effect of acid upon concrete is more complex, and is not alluded to by the author. There are cases where an acid water or an acid sewage has destroyed a cement structure by contact, and also cases where such a contact in no way injured the structure, but where serious injury has been caused by gases above the waters after escaping from them; so that, in one case, the cement has deteriorated only below the water surface, and in the other it has deteriorated only above it.

The great usefulness of cement for water-carrying works, or for foundations in ground-water, makes it quite important and almost imperative to find ways and means of guarding against its destruction by either alkali or acid, and there is no doubt that, at no very distant day, the subject will become sufficiently well understood for all practical purposes.

In the meantime engineers should become acquainted with the facts of experience already known, and the author has done a good work in collating some of them.

The engineer and chemist reporting on the sewer case at Great Falls, Mont., distinctly conclude that "the disintegration of the cement cannot be charged to any action of the sewage or gases from the same." The speaker will refer to the effects of sewage later.

Experiences recorded in Montana, Colorado, and Europe indicate pretty satisfactorily that cement can be completely destroyed by alkaline or acid waters coming in contact with it. Even soft bricks seem to have been affected, but no final explanation is offered. As the same results have followed the use of quite different brands of cement, and in different countries, it may be concluded that the destroying cause is a broader one.

Evidence points strongly to the fact that the porosity of the material aggravates the evil. The mortars used were generally mixed from

Mr. Hering.

1:3 to 1:5, which indicates a sufficient porosity to allow alkaline water to enter by capillarity, and, if under some pressure, as from ground-water standing higher than the drain, to pass through the material into the drain.

The deterioration is generally greater the more porous the mortar, as often found in the interior of the mass, while at the surface the cement often forms a firmer and richer coating, and is very little if at all affected, unless there is merely a white alkaline efflorescence.

These conditions are quite consistent with the conclusion that the surface layers, through plastering and troweling, have been compressed and have had their porosity decreased as the layers were made denser. The absorption of alkaline waters, and therefore their detrimental effect, is correspondingly reduced.

Evidence is available at Great Falls showing that, where the soil in the back-filling over a drain had the highest percentage of alkali, the greatest destruction took place. It is also recorded that the waters flowing in a drain are generally less alkaline than the adjacent ground-waters, which fact is supposed to be probably due to the waters entering the drain having had less time to take up alkaline solutions than the more slowly percolating or standing waters in the soil outside of it.

The author recommends, where practicable, an exclusion of the alkaline soil-waters from a cement drain or sewer by a sub-drain of gravel or stone, which, also, in the speaker's opinion, appears to give the best and cheapest solution.

Professor William P. Headden, of the Colorado Agricultural College, has given a chemical analysis of the original cement and of the material after it had been altered by alkaline water. This is interesting, as it shows the removal of some and the formation of other ingredients, as follows:

| | | |
|---|---|---|
| Removed: | about two-thirds of the alumina | ($Al_2O_3$) |
| | about one-half of the silica | ($SiO_2$) |
| | about one-half of the lime | (CaO) |
| | about one-half of the iron oxide | ($Fe_2O_3$) |
| Formed: | about 12 times the sulphuric acid | ($SO_3$) |
| | about 9 times the carbonic acid | ($CO_2$) |
| | about 3 times the magnesia | (MgO) |

This shows a large accession of sulphuric and carbonic acids, and the conclusion to be drawn from this alteration is that the most active agent in the decomposition of the concrete was the sulphuric acid of the sulphates carried by the waters in solution, that the carbonic acid came next, and the accession of magnesia last. This result corresponds in general with others derived elsewhere.

It has been known for some time that sea water has deteriorated cement by the action of the sulphates contained in it, chiefly by the

Mr. Hering.

final formation of calcium sulphate, which by crystallization expands and mechanically disintegrates the mass. The precaution usually considered is the making of a denser and richer mixture in order to prevent the sea water from penetrating the mass, which conclusion is in harmony with that reached by the author and others for protection against alkaline ground-waters.

The only other preventive seems to be that which is intimated by the author in closing, namely, the external application and a partial incorporation of some impervious coating. Many coatings have been suggested to effect this purpose, and some have been used with moderate success; but, as yet, there is no consensus of opinion regarding the best.

No doubt different coatings may probably be found best under different conditions. Manufactured and thoroughly dried cement pipe may perhaps be coated with a material which would give satisfaction, but would not answer for a pipe made in the trench. The only coating which will give permanent satisfaction is one which will be effective upon a damp structure, and will incorporate itself so thoroughly with the cement that peeling or scaling off is impossible. It is hoped that such a material may soon be found. A lining composed of vitrified tile plates has been proposed for the purpose in the West, and, thus far, barring the expense, it appears to have given satisfaction.

The speaker has mentioned the effect of acid upon concrete structures as being complex, so far as it is governed, not only by an acid in the liquid, but by gases subsequently arising from it. An acid liquid, as in the case of the sewage sometimes discharged from factories, is known to disintegrate cement pipe. The preventive, as in the former case, if practicable, is to exclude the objectionable element, or to give the cement a protective coating or lining.

The effects of the gases produce an entirely different condition. The most serious of these is that of the sulphuretted hydrogen which may be converted into sulphuric acid in the sewer above the water, and in some cases, as found in a Los Angeles sewer by the City Engineer, Homer Hamlin, M. Am. Soc. C. E., sulphur crystals adhere to the bricks of which the sewer was built.

The Los Angeles sewage produced no deterioration of the cement below the water surface, the speaker finding it hard and sound. This condition differed radically from the effects of alkaline sewage where the deterioration was chiefly below the water surface. The escaping sulphuretted hydrogen was converted into sulphuric acid within a short distance of its escape from the sewage, as was distinctly discernible on the surface of the brickwork in the arch. This acid transformed the carbonate of lime in the cement joints into sulphate of lime, a soft friable gypsum, which gradually caused the complete destruction of the binding quality of the mortar.

Mr. Hering.

In this case, no doubt, a good forced ventilation might have prevented the formation of sulphuric acid, or the sewer might have been given a vitrified lining, or at some time it may be possible to apply a coating which will protect sewers from this sort of destruction. In Los Angeles, for other reasons, the sewer was abandoned for one built in another locality.

Some interesting experience in this direction is reported from Germany.

In a Berlin brick sewer, where the mortar was a 1:3 mixture, flakes up to ½ in. in thickness and 2 in. in diameter peeled off the bricks. The thickest peeling was at the cement joints. Upon the mortar was observed a soft white material (gypsum) looking like freshly made lime mortar. Below the water level, the mortar and the bricks were sound, as they were in the Los Angeles case.

To ascertain the cause of this trouble, experiments were made by hanging in the sewer, well above the water level, samples of three materials: marble, cement mortar, and pulverized carbonate of lime. The results are given in Table 3.

TABLE 3.

| Sample. | Percentage of $SO_3$. | | | | |
|---|---|---|---|---|---|
| | When suspended in sewer air. | | When observed. | | |
| | | | May, 1897. | Jan., 1898. | May, 1901. |
| Marble | November, 1896 | 0.019 | 0.051 | 0.420 | ..... |
| Cement mortar | February, 1897 | 0.116 | 0.200 | 0.440 | 0.640 |
| Carbonate of lime | " " | 0.010 | 0.048 | 1.440 | 2.760 |

It was found that the sulphuric acid contents in these materials were increased in quantity, as follows:

In the marble, in 14 months, about 20 times;

In the cement mortar, in 11 months, about 4 times;

" " " " in 4 years, about 6 times;

In the carbonate of lime, in 3 months, about 5 times;

" " " " " in 11 months, about 140 times;

" " " " " in 4 years, about 250 times.

In the summer of 1901 an analysis of the sewer air gave 200 parts in volume of sulphuretted hydrogen per million parts of air, which was considered an average condition.

At the sewage department of Charlottenburg (Berlin), equal parts of sulphuretted hydrogen and air were passed through cotton at a temperature of 30° cent. (85° Fahr.). Water was then filtered through it, and the presence of sulphuric acid was demonstrated. As a further

Mr. Hering.

demonstration, a thin water layer covering the bottom of a closed bottle and containing some fine sulphur powder suspended in it, on being exposed to a temperature of from 20° to 30° cent. for two weeks, showed a strong reaction of sulphuric acid.

That sulphur is formed directly from sulphuretted hydrogen is shown by the fact that sulphuretted hydrogen when dissolved in water frequently shows sulphur powder on the surface formed by oxidation ($H_2S + O = H_2O + S$); and very fine sulphur powder exposed to air and water is known to be directly converted into sulphuric acid ($S + 3O + H_2O = H_2 SO_4$).

The Berlin examinations, therefore, give a confirmation of and an explanation for the Los Angeles case. The sulphuretted hydrogen escaping from the sewage rises to the brick arch, which has a coating of moisture condensed upon the surface. The air converts it first into sulphur, and this is subsequently converted into sulphuric acid.

It had been suspected that bacterial action was responsible for the latter conversion, but Winogradski, in his work on "Sulphur Bacteria," reports that he obtained the same result without it.

It is interesting to add that in 1897, when the foregoing experiments began, the bricks were also subjected to analysis. The porosity was found to vary from 8.5 to 14.3% in bricks of different manufacture. All bricks showed on the surface white exudations of carbonate of lime, but they were very slight upon the densest and very marked upon the most porous brick, and in the latter case the pieces could be easily taken off with a knife.

This phenomenon is explained by Bretschneider as follows: From the layer of moisture on the brick the sulphuric acid enters the pores and is diffused by capillarity through fine cracks and the pores into the interior of the mass. It converts the lime into gypsum, which by this conversion is doubled in volume. Unless the material of the brick can resist the resulting expansion, when some of the gypsum oozes out to form a coating, it cracks and peels off, as above mentioned, to the depth to which the sulphuric acid has formed the gypsum.

It has been observed that the destruction of mortar does not progress in an arithmetical ratio, but gradually decreases, as indicated in Table 3. This is partly explained, also by Bretschneider, by the increased ventilation through additional house connections, which in Germany are used as sewer ventilators, the greatest destruction taking place where there were fewest connections. Secondly, he believes that the percolation of ground-water through the sewer masonry gradually decreases by a closing of the pores on the extrados of the arch, and finds that the surface of the bricks on the interior thus becomes dry and the formation of sulphuric acid ceases.

In Osnabruck, Prussia, a sewer was built in peaty ground in 1903, the ground-water level standing about at the springing line. In half

a year signs of destruction were visible, and within several years it became serious.* The cause of the disintegration was laid to iron pyrites ($FeS_2$) which formed 17% of the peat. The greatest destruction was found on the outside of the sewer and between high and low ground-water level, which is explained by the fact that the conditions for an energetic oxidation were most favorable when both air and water were present at the same time. The least destruction, in fact, almost none, was observed in the interior. Mr. Hering.

This case is explained by some as being due to the pyrites being oxidized in contact with air into free sulphuric acid ($SO_3$) and sulphate of iron ($FeSO_4$), and by the further fact that the ground-water contained from 8 to 87 parts per million of free sulphuric acid.

The same case is explained differently by Bretschneider. He maintains that the destruction of the cement mortar required that a sufficient amount of sulphuric acid should form directly upon and in the structure, and believed the acid dissolved in the ground-water was too weak for the purpose. He assumed that the sulphuretted hydrogen contained in the ground-water, which is abundant in the peat, rises into the pores of the damp soil around the structure, and is there first converted into sulphur, as above mentioned, and then, after being exposed to more air and more moisture, there is a further conversion into sulphuric acid, when adjoining the structure or when absorbed into the same. It will be seen that in Osnabruck, the disintegration resulted from acid peaty water and also from sulphuretted hydrogen gas.

Structures in Charlottenburg have been protected against injury from sulphuric acid and other organic acids in peat or similar soils by a complete covering of three layers of asphalt paper.

The foregoing data seem to indicate the following inferences:

1.—When the immediate agent of destruction is carried by water, disintegration will be found below the permanent water surface. If such water is flowing inside of a structure, as in a sewer (acid or alkali factory waste), the disintegration will be inside and as far as the water penetrates the material. If the water is ground-water in alkali soil, swamp or peat, the disintegration will be on the outside (Great Falls and Osnabruck), and chiefly between high and low ground-water levels, and may penetrate porous material toward the inside of the structure.

2.—When, on the other hand, the agent of destruction is caused by gases (generally sulphuretted hydrogen) arising from waters, whether on the outside (Osnabruck) or the inside (Los Angeles and Berlin) of a structure, the disintegration will take place above the permanent water surface.

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*City Engineer Lehmann, in *Deutsche Bauzeitung*, 1908, p. 467.

Mr. Humphrey.

RICHARD L. HUMPHREY, M. AM. SOC. C. E.—This subject is exceedingly interesting, particularly as it concerns apparently the stability of those great structures which are being executed under the direction of the United States Reclamation Service in the West. The subject, however, is not a new one. Investigations of the effect of alkali on concrete and other structural materials have been in progress for many years, especially in Europe, where they were inaugurated 30 or 40 years ago. Recently, the investigations at Great Falls, Mont., by the Montana State Agricultural College, have given a fresh impetus to the study of alkali action. The United States Geological Survey became interested, and in co-operation with the Reclamation Service and other investigators, undertook a systematic investigation.

It has been the speaker's good fortune to visit the various districts referred to by the author, as well as the places in Europe mentioned by Mr. Hering. While the investigations by the Geological Survey cover all portions of the Reclamation Service work, they are being particularly directed to those in the vicinity of Great Falls, Mont., the only ones, thus far, which have furnished examples of the deleterious action of alkali on various building materials.

In studying the conditions in those districts where alkali action has produced destructive results, it has been the practice first to make an analysis of the water used in irrigation work, of the materials used in construction work, of the soil, and of the various efflorescences to be found on the soil and on the structure attacked, the object being to determine the salts present and then to study the effect of individual salts and of mixtures of several salts, on the various structural materials. The investigation has for its object an attempt to reproduce in the laboratory the destructive effects observed in the field.

Having ascertained the salts which produce this destructive action, and the conditions under which it can take place, an effort will be made to discover some means by which it may be prevented, either by (1) neutralization, that is, by the admixture of some substance which will prevent the action; or, (2) insulation, that is, by the application of some material which will render the structure immune.

It has been found that the action may be prevented by proper drainage, and, in the case of concrete, by securing a maximum density and giving the exposed surfaces a granolithic finish.

The speaker is of the opinion that Mr. Hering has not been correctly informed as to the damage in the districts referred to by the author occurring below the water line. He is fully convinced that the action occurs at the ground-water line, and, further, he believes that it is largely mechanical and the result of rapid evaporation due to the extremely dry atmosphere. The water used for irrigation purposes does not affect the structures; it is the water draining through the alkaline soil which causes the damage. The speaker has found that

Mr. Humphrey.

the alkali action is confined to the water line, there being no indications of this action where the structure is wholly submerged. The same is also true in the case of sea water, the action occurring between tides. This is especially true where frost action has occurred.

In the first experiments made by the Geological Survey, notwithstanding the fact that very porous test pieces were used, with the expectation of obtaining rapid action, difficulty was experienced in securing any action; but when the test pieces were subjected to currents of warm dry air, the action became quite rapid. The speaker believes that this is the condition which prevails in the arid regions of the West; the rapid evaporation of the ground-water (carrying the alkalis in solution) in the hot dry air of the plains, produces a rapid crystallization which, occurring in the pores of the structure, results in a gradual disintegration. This action is quite similar to that of frost. Therefore, the speaker is of the opinion that while this action is probably both chemical and mechanical, it is largely mechanical.

Thus far the waters used for irrigation purposes have not shown a deleterious action on the structures with which they have come in contact. In his investigations the speaker has found that it is the water which percolates through the soil, and becomes saturated with the alkali, which causes disintegration, through the crystallization resulting from rapid evaporation. These conditions, reproduced in the laboratory, have given similar results.

This action is not confined to cement structures alone, but occurs in those of stone and brick as well. Generally, it is found where the brick or stone is quite porous, and has a high absorption. In such structures the disintegration occurs at the ground line or at that point above it which marks the limit of capillary action, where the water evaporates.

The manner in which the work on the various Reclamation projects has been executed, has been referred to as first-class. As far as the speaker's investigations have extended, this has been found to be true, but attention is called to the fact that, while the workmanship is first-class, it does not necessarily follow that the materials used have been of maximum density. It is found that one essential for resistance to alkali action is that the material shall have a minimum absorption. Concrete, therefore, must be very carefully proportioned in order to produce the densest mass possible. It is also believed that the stronger the concrete, the greater is its resistance to the action of alkali. This condition may be attained by rich mixtures and by age in the concrete.

It is not always practicable to maintain ideal conditions which will result in dense, relatively impervious structures, and it is often difficult to secure the density desired, but, with reasonable care, these conditions may be fairly well maintained.

In connection with these investigations of the effect of alkali, the

Mr. Humphrey.

Geological Survey is also studying the effect of the action of sea water on various structural materials. For this purpose a special laboratory has been established on Young's Old Ocean Pier, at Atlantic City, N. J., where various cements are being studied, including those reputed to possess great resistance to the action of sea water.

The preliminary experiments consist in agitating the dry, unhardened cement in bottles containing sea water and also fresh water, and studying the change in the composition of the cement. Thus far, the experiments show that the cement gains in magnesia content and loses in lime content. This is also true of hardened cement reduced to a powder and similarly treated, although the action is slower. The action on large test pieces of hardened concrete, wholly submerged, or placed so as to be submerged only at high tide, is also being noted.

Where concrete is deposited in moulds through sea water, the disintegrating action is very great. On the other hand, if the test piece is moulded in air and allowed to harden for some hours before immersion in sea water, there appears to be little if any action, provided the concrete is properly proportioned so as to secure maximum density. The action of sea water seems to be similar to that of the alkalis.

Attention is directed to a certain phase of this question, namely, that when one considers the particular cases referred to by the author where this action has occurred, the subject assumes a serious aspect, and one loses sight of the fact that such action is of rare rather than of common occurrence.

It is a fact that many structures built in alkaline soils have endured perfectly for many years; there are also numerous structures which have similarly withstood the action of sea water. In fact, the speaker, in his examination of structures in the United States and in Europe, some of which have been built for more than 60 years, has found but one or two instances where such action appears at all likely. Invariably the damage has been the result of bad workmanship or poor materials. There is no doubt that the character of the workmanship is an important factor in the stability of structures subjected to the action of the alkalis or of sea water.

Whether or not a material will be discovered which, when incorporated in the cement mixture, will prevent this destructive action, or whether it can be practically applied, is problematical, but that the structure may be insulated against such action, seems not only probable, but also feasible. It is along this line that the Geological Survey investigations are directed. These investigations have not progressed sufficiently to justify any attempt at conclusions, and these facts are presented in order to indicate that the subject is being carefully investigated, and to state that it is expected that a preliminary report on the work thus far accomplished will be shortly available.

The test of time, after all, must be depended on for conclusive

results, and is essential in the final study. The speaker was impressed by the fact that in European laboratories similar investigations extend over periods of many years. The investigations are planned so that the tests will be continually falling due, up to 50 or more years. This is in striking contrast to American practice, where short-time tests are the rule. Mr. Humphrey.

These investigations by the Geological Survey are of especial value to the Government, as they concern the stability of numerous Federal structures already constructed, and the dry docks, quay walls, and other structures either under construction or contemplated. It is expected that, as a result of the investigations, the stability of structures subjected to such action can be assured. The preliminary work has shown that, where reasonable precautions are taken to secure a maximum density in the concrete and to allow sufficient time for hardening before subjecting it to the action of alkalis or sea water, there is little danger of disintegration.

The speaker desires to state, for the information of Mr. Morse, that there are several kinds of chats; there is a hard chert having a flinty character, and there is a softer limestone, the latter generally containing sulphides. The former makes an excellent material for concrete. The presence of sulphides, however, causes disintegration of the concrete, as the speaker has found by experience. The oxidization of the sulphides also produces a rapid corrosion of embedded metal and is, therefore, particularly undesirable in reinforced concrete.

GEORGE F. MORSE, M. AM. SOC. C. E.—This paper merely touches on the subject of alkali in water used for mixing concrete, and though the following statements cannot properly be called a discussion, it is thought that they are of enough interest to the Profession to be recorded. Mr. Morse.

While building concrete piers for a railroad bridge across the Arkansas River, near Muskogee, Okla., an instance came to the speaker's attention which seemed to indicate that alkali alone in the water used in the mix does not always have a detrimental effect on the concrete. In this case, two piers, identical in every way, except for the coarse ingredient used, and built simultaneously, showed very different results. One pier was built of gravel taken from the river bed, which produced a good concrete. The other pier was built of Joplin, Mo., chats, and was a total failure, as the concrete did not set. The pier was afterward taken down. The "concrete" was of about the consistency of semi-cemented gravel, and was easily excavated with pick and shovel. In both instances water containing alkali (and from the same source) was used, the sand and cement being identical.

Subsequent experiments with the chats, using water free from alkali in the mix, produced excellent results; but, when alkaline water

Mr. Morse. was used the concrete failed to set. The same result was obtained in three other instances, where similar conditions prevailed.

Attention is called to the fact that in the Southwest chats are very commonly used in making concrete, with excellent results; in fact, the speaker had used them in reinforced concrete work before these bridge piers were constructed. If it had not been so evident that the chats were at fault (as shown by the opportunity to compare the result with concrete containing other coarse ingredients), there would have been no reason to suspect the real cause of the failure.

It is customary for engineers to look well to the character of the cement, sand, and water used in concrete work, and to be satisfied with the coarse ingredient, if it answers the physical requirements. It is evident from the foregoing that in this case some chemical action between the alkaline water and the chats caused failure.

Mr. Gaines. RICHARD H. GAINES, ESQ.*—Interest in this subject is not confined to the West. The evidence presented by the author abundantly demonstrates the destructive action of alkaline waters on cement, tiling, and concrete. The question is no longer one of bad specifications or poor construction; but special measures of protection, yet to be devised, are necessary to meet the conditions outlined. A difficult problem is submitted to the Engineering Profession, and the vital importance of its solution cannot be emphasized too strongly. Few are aware of the extent of the great region, west of the Mississippi, which is marked by the presence of alkali in the soil or on the surface.

The decomposition of mortars exposed to the action of waters charged with sulphates has long occupied the attention of chemists and engineers, and many experiments have been made in order to discover some hydraulic binding material which would not be subject to deterioration. Until within a few years, these researches have been concentrated chiefly on the injurious action of sea water, although the destructive effect of sulphates of lime and magnesia was not unknown. The difference between sea water and the alkaline waters of the West is that the latter act more energetically, owing to a much greater concentration of the sulphates of magnesium and calcium, and, as their name implies, they contain, in addition, alkaline carbonates.

Notwithstanding the title of the paper, nothing is said of the effect of the presence of the alkali constituents of the waters. These strong bases react with the aluminate in cement, resulting in acid-forming oxides.

It is desirable to have a clear conception of the chemical changes which tend to destroy concrete when in contact with sulphate or alkaline waters. The basic calcium aluminate in set cement is believed to be the vulnerable point of attack, and is where the mischief is done. With this constituent the sulphates form sulpho-aluminate of

* Chemist, New York Board of Water Supply.

lime, a reaction attended with a great increase in volume (owing to the water taken into combination), and consequent disruption. Both magnesium and calcium chlorides, wherever present, are detrimental to concrete, owing to the fact that the chlorine radicals replace the aluminate, causing the production of soluble compounds. In a series of experiments on immersed briquettes with artificial solutions of various salts, recently conducted by the speaker, the injurious action of chlorides of calcium and magnesium was fully confirmed. Sulphate solutions, however, appeared from the experiments to be the most active decomposing agents. Mr. Gaines.

The experience cited, of numerous concrete failures in the West, teaches that engineers must be on the alert for saline waters wherever construction is planned or under way. In fact, waters almost saturated with salt solutions are sometimes found far from alkaline regions or any recognized occurrence of gypsum. On the other hand, drain waters which, at certain times, contain small quantities of sulphates, may become saturated during periods of drought. Subterranean waters should always be examined for sulphates and chlorides of calcium and magnesium, if they are to flow in contact with concrete. Waters encountered in the older strata in several parts of the country, both East and West, have been found to be heavily impregnated with these injurious compounds.

According to the partial analyses published, the ground and drain waters from the trans-Mississippi region do not differ greatly in composition from the sulphate waters which have proved destructive to mortars in Spain, France, and other parts of the world. In France, especially, considerable attention has been given to the study of this problem during the last few years, and some valuable results have been obtained. There, it has been found that the pozzuolanas have always had a notably ameliorating effect where sulphates were encountered. The best resistance values were obtained with mixtures of silicious cement and dehydrated clay in the proportion of 1 part of clay to 1 part of cement. Calcined clay seems to be the most energetic of all the artificial pozzuolanas. Vicat estimated the appropriate calcination temperature of clay at about 1 000° cent., but it should be emphasized that the operation of dehydration is industrially a delicate one; if the desired temperature is not realized, either by exceeding or by not reaching the proper calcination heat, an inert material instead of a pozzuolana may be manufactured.

Experiments by M. Bied, of Le Teil, Department of Ardèche, France, reported to the last meeting of the International Society for Testing Materials, confirm the superiority of silicious cements over aluminous cements, and the favorable effect of the addition of dehydrated clay. According to Bied, in the presence of sulphate of calcium, the use of dehydrated clay is the only means known at present

Mr. Gaines.

of preventing decomposition. The addition of the clay cannot be made on the work, but must be entrusted to conscientious manufacturers. The addition of stearate of lime and similar compounds to ordinary cement, which render the mortars more impermeable, were shown to be inefficient in preventing decomposition.

For a number of years the large French company, the Société J. et A. Pavin de Lafarge, claims to have supplied an indecomposable cement based on a mixture of dehydrated clay and the silicious cements made by that firm. This engineering and contracting company constructed the great military harbor works at Bizert, the French military base opposite Corsica, on the African Coast, and is well known in Europe. The cement made by this firm has been used throughout the gypsiferous territories of Southern France.

The promising results obtained in France should lead to experiments along the same lines in America, and such experiments should be made in as many laboratories as possible. A method, at once sure and rapid, of determining the capability of cement mortars to resist the decomposing action of alkaline or sulphate waters, has not come into general use. The method hitherto used commonly consists simply in immersing the mortar in the saline water and observing it for as long periods as possible. The results obtained by this test vary, however, according to the composition of the mortar and the conditions of its immersion, and the experimenter often has to wait long periods before signs of disintegration are observed, and even then such signs may be of a doubtful nature. There is room, therefore, for the proposal of some scientific and expeditious method of arriving at the relative resistance values of different hydraulic materials which may be subjected to the action of sulphate or sea waters.

Until a cement is discovered which is proved to be capable of permanently resisting the destructive effects of these alkaline waters, the safest policy will be to follow the recommendation of Candlot concerning sea water, and to consider their action from a purely physical standpoint. By thus eliminating the chemical side of the problem, the only remedy to be adopted against decomposition is some physical means of preventing the water from penetrating the mortar.

The speaker recently had occasion to study the possible effect on concrete of a deep subterranean water which was heavily charged with the sulphates and chlorides of alkali and alkaline earth metals. Preliminary experiments having indicated energetic decomposing action on hardened cement mortar, a series of accelerated tests was made in order to determine what salts present in the water set up the destructive chemical changes. After ascertaining by analysis the saline constituents of the water in question, a number of definite solutions of chemically pure salts were prepared, each containing separately, in distilled water, the individual constituents found in the natural water.

Broken neat and mortar briquettes were immersed in beakers in these solutions and allowed to remain at room temperature for 10 days. For comparison, specimens were kept in some of the subterranean water for the same length of time. The list of pure salts in separate solution included: Mr. Gaines.

Magnesium sulphate,
Calcium "
Sodium "
Calcium chloride,
Magnesium "
Sodium "

The tests also included the action of salts not found in the natural water, but commonly occurring as constituents of other saline waters that have proved destructive to concrete. These were the sulphates of iron and aluminum, the carbonates of sodium and potassium, and the bicarbonate of sodium.

At the end of the test period, precipitates were found in all the beakers in which the mortar specimens had been in contact with solutions of sulphates, the action having been most energetic in the presence of sulphates of calcium and magnesium. Considerable precipitation also occurred from contact with the magnesium and calcium chloride solutions, the latter proving as actively decomposing as any of the salts. The alkaline carbonates were apparently without effect, as also was sodium chloride, but sodium bicarbonate caused some action. In none of the separate solutions was the decomposing action comparably as energetic as resulted from contact with the subterranean water, which, as previously stated, contained a natural mixture of chlorides and sulphates of calcium, sodium, and magnesium. A qualitative examination of the solutions and material thrown down from the mortar specimens in the form of precipitates, in the beakers where action was apparent, showed that the alumina, lime, and iron oxide in all the specimens had been attacked to a greater or less extent by the solutions.

While the conditions of this series of experiments were not such as to lead to definite conclusions in a quantitative sense, the results obtained serve to show from what ingredients in saline waters danger may be expected; and thus they have a very direct bearing on the study of the question of the effect of alkaline, sulphate, or sea waters on concrete.

Several authorities, including Michaelis, have stated that if alumina in cements is replaced by ferric oxide, the deleterious effect of sea water is prevented. Brief experiments made by the speaker with a sample of so-called iron ore cement received from Germany (in which ferric oxide almost wholly replaces alumina), indicate that while this

Mr. Gaines. material is apparently unaffected by sulphate waters, it offers no greater resistance to the attack of calcium and magnesium chlorides than ordinary Portland cement. In practice, whatever cement may be used, all alkaline and sulphate waters should be kept from contact with fresh concrete until it has gained substantial strength.

Mr. Means. THOMAS H. MEANS, M. AM. SOC. C. E. (by letter).—This paper brings before the Society a subject which is worthy of careful consideration. Recently a number of articles have appeared in the public and engineering press, which would lead the uninitiated to believe that, in the soil of the West, concrete is not permanent. That there is no need for such apprehension is apparent, of course, to anyone well acquainted with the circumstances, but there are so many people who are not, that a few words of reassurance may not seem amiss.

This subject was brought prominently before the public in bulletins issued by the Experiment Stations of Montana and Colorado. Each of these publications describes cases of failure of concrete, and each presents the results of some chemical work.

It is unfortunate that the results of these investigations, made on specific cases of failure of concrete, should have been given such general application. No general failures have occurred in the West, in fact, there have been very few, when the great extent of cement structures in engineering work is considered. For many years cement has been used in irrigation and drainage work in arid and semi-arid regions, not only in the United States, but the world over, and very few failures have been reported.

For nearly twelve years the writer has been associated with work in the Arid West, much of the time in connection with alkali-soil investigations, and, during this period, work has been carried on in every arid State. From the first he has watched the effect of various alkalis on cement, brick, stone, and other building materials. However, no special investigations were made in order to solve the problem. Wherever a certain alkali has been found, a deleterious action on cement has been noticed. The severity of this action seemed to depend on the quality of the concrete, on the strength of the alkali solution, and, to a certain extent, on the exposure of the concrete. Other alkalis do not seem to have any serious effect on concrete, in fact, a number of cases have been under observation where concrete has been exposed for several years to intensely alkaline soils with no bad results.

The alkali which seems most harmful generally contains sodium and magnesium sulphates, chlorides, and some gypsum or calcium sulphate; other salts occur in greater or less quantity.

As far as observations without analyses are of value, it is apparent that the magnesium soils are the most deleterious, and this view is

supported by the experience of others. Chlorides alone do not seem to be harmful, and sulphates of sodium and calcium are not harmful. On the Truckee-Carson Project, in Nevada, there are areas of land which contain large quantities of sodium sulphate and sodium chloride mixed. On this project a great many concrete structures have been built; 50 000 bbl. of cement have been used, some of it having been placed in strong alkaline soils, and a careful examination of structures five years old has failed to reveal any disintegration of the concrete. Mr. Means.

Carbonate of soda or black alkali is the most harmful salt, as far as vegetation is concerned, and it is likewise the only alkaline compound, in the chemical use of the term, ordinarily found in soils. It has been said that this salt, on account of its alkaline reaction, would have a solvent action on cement, but such does not seem to be the case. Apparently, black alkali alone is not harmful to concrete. Big Soda Lake, near Hazen, Nev., is an important source of natural soda. The water carries about 12½% of solids in solution, and of this more than 7% is sodium chloride, nearly 2% sodium sulphate, and more than 2½% sodium carbonate. Specimens of cement pipe, which have been in contact with this water for several years, show no signs of deterioration.

It is true that very porous concrete is apt to be damaged by alkaline waters of any kind, but good concrete seems to be free from damage by any but alkali containing magnesium salts. No evidence is at hand to show that any particular brand of cement is more susceptible to damage than others, but it is not to be expected that such would be true, for all reputable brands have nearly the same composition.

Besides the chemical action which magnesium compounds seem to have, there is a mechanical disintegration which seems to be most active in porous concrete. The crystallization, solution, and recrystallization of salts seem to loosen up the concrete and disintegrate it by prying off outside grains.

The harmful alkalis seem to be found almost always in certain cretaceous formations of the Rocky Mountain States. Pierre shale and formations associated with it, seem to be the main source of soluble magnesium salts. This geologic formation occurs in a number of Western States, and where the soluble salts have not been leached from the soil, cement and concrete work is apt to be badly affected.

No doubt there are other localities where deleterious compounds exist. Evidence of this can often be obtained from the State Experiment Stations or from the Department of Agriculture, at Washington.

Thus far, no very satisfactory remedy has been proposed. There is an excellent opportunity for an extended investigation of the physical and chemical phenomena connected with the effect of alkali on concrete. Magnesium compounds seem to have many peculiarities.

Mr. Means. It may be possible that a cement of some peculiar composition may be developed, which will not only resist the disintegration and decomposition caused by magnesium salts, but will be more satisfactory for use in sea water. Again, it may be possible either to protect concrete made with commercial brands of cement, by some special precautions, or to introduce some foreign substances into it in order to prevent damage. The field certainly looks promising for some enterprising chemist or physicist.

Mr. Robertson. F. E. ROBERTSON, ESQ. (by letter).—Alkali is to be found in many parts of India, where it is known as *reh* and *oosur,* and regular alkali deserts occur in Sind and on the Northwest Frontier. Under certain circumstances the salt is most destructive to materials which would stand well enough ordinarily, but the cause and remedy are well known. The salt crystallizes in the pores of the material and disintegrates it by an action somewhat similar to that of frost. Bricks are speedily reduced to powder, as are also soft stones and concrete. The mortar used in those parts of India where alkali occurs, is made of one part of fat lime ground finely with two parts of pounded brick, called *soorkhi.* It is moderately hydraulic and well made, and, when laid, eventually becomes as hard as bricks; it is likely to be destroyed, however, by the effect of alkali. Even fire-clay goods, if underburnt, are likely to be destroyed, one end of a pipe being reduced to powder while the other end remains uninjured. For building, and for making *soorkhi,* nothing should be used but slightly vitrified brick—at all events on all external surfaces—and concrete with an impervious skin.

The author states that:

"These failures may indicate some special peculiarity of the local soil, and may be somewhat similar to the well-known fact that the action of sea water has been destructive to concrete in certain localities and not in others."

In regard to this, it is not the action of the alkali or the sea water which varies from place to place, but the structures acted on. Underburnt brick and porous concrete will perish whenever they come in contact with alkali or sea water.

The tile mentioned as made of 1:5 mixture was certainly very porous, and it is improbable that the voids in any sand are less than one-third, which, to be safe, would demand a mixture of 1:2½.

Mr. Bates. PHILO H. BATES, ESQ.* (by letter).—Mr. Anderson's paper on the effect of alkali on concrete, gives an interesting résumé of the subject. One noticeable feature is the agreement by all that this action is similar to, or identical with, that of sea water in effecting the disintegration of concrete. This may be true, for in alkali, alkaline

*Chemical Engr., Technologic Branch, U. S. Geological Survey.

waters, and sea waters, the same salts are found, though the proportions of the salts are very different, as, for instance, the very slight quantities of chloride and the large quantities of sulphates in alkaline waters, and the reverse in sea water. Which of these salts causes disintegration, or which is the most active in this respect, however, is a matter of considerable doubt. Mr. Bates.

The Structural Materials Testing Laboratory of the United States Geological Survey has recently undertaken some experiments which are still under way, and by which it is hoped to define what salts or combinations of salts cause disintegration of concrete and kindred structural materials. Moreover, it is hoped to determine whether this action is caused by chemical or physical changes, the former resulting from the reaction of the salts in solution with the constituents of the cement, and the latter from the freezing or crystallizing of the salts from their solutions in the pores of the concrete. Many engineers are acquainted with the action of the freezing of water in concrete, and its results, where there is no chemical reaction. Without acknowledging any chemical reaction, it can be readily understood that the result of the formation of crystallizing salts in concrete is to cause them to occupy a greater volume than their solutions. Chemical action does take place, however, when the magnesia salts are present in the solution, as the lime liberated from the cement by its setting replaces the magnesia, the latter appearing as a gelatinous mass. It might be considered that this mass thrown out over the particles of cement would protect it from further action. The salts in black alkali, largely sodium carbonate, have a chemical action which involves the formation of calcium carbonate.

Bulletin No. 132, of the Montana Agricultural College, gives an excellent description of the condition of the sewers in Great Falls, which city is located in a very alkaline region, where the salts are sodium or magnesium sulphates, or combinations of these two. It is noticeable that these sewers are principally of brick, and that they are badly disintegrated. This brings up a feature which has been little emphasized before, namely, the action of salts on brick and stone. No matter whether the action is physical or chemical, it cannot be assumed that concrete will be attacked and not other porous material. The writer has seen samples of brick and sandstone, removed from buildings in Great Falls, which could be powdered in the hand. He has also examined the bottom of irrigation ditches excavated in Oregon sandstone, in which the stone has retained its original form and appearance, but could be crushed readily in the hand. It would seem, therefore, that the problem is not limited to cement products, but should include all building material which might be used in a similar manner. Consequently, in its investigation of this destructive action, the Geological Survey has included also building stone and clay products.

Mr. Bates.

In the investigations now under way, there are being used, in the preliminary experiments, solutions of sodium chloride, sodium sulphate, sodium carbonate, magnesium chloride, magnesium sulphate, and iron sulphate alone; also solutions containing equal parts of sodium chloride and sodium sulphate; sodium chloride and magnesium chloride; sodium chloride and magnesium sulphate; sodium sulphate and magnesium sulphate; magnesium chloride, magnesium sulphate, sodium sulphate, and magnesium chloride; and also sea water from Atlantic City.

These solutions are being used in two series of investigations; the first, purely chemical, consists in shaking up a definite quantity of cement with a definite quantity of solution, then withdrawing the solution at intervals, and, by analysis, determining what the cement has lost or gained. At present this is being conducted with an unset cement. Later, the test will be repeated with a set cement. The second series is physical, and consists of making hollow cylinders of cement mortar and hollow cylinders of burned clay, closed at one end. Through these the various solutions are allowed to percolate, the appearance of the cylinders being noted from time to time. From this the relative disruptive force of the different solutions may be determined. In the first experiments of the second series a very rich mortar was used, dry mixed, in order to give a very porous product, rich in cement. From this it will be possible to determine whether any of these salts can be omitted in the further investigations owing to their slight action. Hereafter, other cement mortar cylinders will be made, less rich and more dense mixtures being used. Specimens will also be made to which, after setting, different quantities of salts will be added in solution, and an attempt made to determine how much is necessary to cause disruptive action. By keeping other cylinders immersed in the various solutions, and noting the action or want of action, and then drying and noting the effects, it is hoped that some valuable preliminary information will be procured on this interesting and difficult problem.

The very dry atmosphere of the region where alkali is most plentiful and where the action has been reported to be most severe, naturally suggests that it would cause excessive evaporation and result in excessive crystallization.

These investigations are being prosecuted in the hope that a method of preventing this action may be evolved. This will necessitate tests of various water-proofing materials, and these have been in progress by the United States Geological Survey for more than a year. A very important class of these materials, known as bitumens, and including coal-tar, pitch, asphaltum, and petroleum residuum, is being examined. The investigation would also be incomplete without considering the use of pozzuolana, slag, and iron-ore cements alone or replacing a portion of the Portland cement.

Mr. Goodrich.

E. P. GOODRICH, M. AM. SOC. C. E. (by letter).—Somewhat more than a year ago, for the benefit of one of his clients, the writer made some experiments of the effect of several different alkalis on small concrete cylinders immersed in various solutions, and of the benefits derived from two methods of water-proofing concrete which are in use. The cylinders were about 3 in. long and ½ in. in diameter. They were mixed with Portland cement and ordinary bank sand of good quality in the proportions of 1 part cement to 2 parts sand, except that one specimen was moulded with neat cement for immersion in each of the solutions considered. The latter included sodium chloride (NaCl); magnesium sulphate ($MgSO_4$); calcium sulphate ($CaSO_4$); sodium sulphate ($Na_2SO_4$); and pure water for comparative purposes. Ten grains of each of these materials was dissolved in a pint of water, in air-tight glass cans, and the cylinders were immersed therein, on February 6th. The cylinders were removed, weighed, and replaced on February 9th, March 19th, April 21st, May 30th, and the following March 29th, respectively.

TABLE 4.

| | February 9th. | March 19th. | April 21st. | May 30th. | March 29th. | | Average. |
|---|---|---|---|---|---|---|---|
| $H_2O$. | 15 | 15 | 5 | 5 | 20 | Neat | 12.0 |
| | 10 | 16 | 10 | 5 | 16 | Mortar | 11.4 |
| | 13 | 17 | 22 | 9 | 22 | Powder | 16.6 |
| | 0 | 12 | 12 | 4 | 20 | Wax | 9.6 |
| | 9.5 | 15.0 | 12.2 | 5.6 | 19.5 | Average | 12.4 |
| NaCl. | 23 | 18 | 12 | 23 | 23 | Neat | 19 8 |
| | 8 | 17 | 8 | 17 | 5 | Mortar | 13.0 |
| | 10 | 20 | 7 | 12 | 12 | Powder | 12.2 |
| | 6 | 6 | 0 | 6 | 10 | Wax | 5.6 |
| | 11.8 | 15.2 | 6.8 | 13.0 | 12.5 | Average | 12.6 |
| $MgSO_4$. | 28 | 32 | 9 | 18 | 18 | Neat | 21.0 |
| | 35 | 20 | 0 | 20 | 20 | Mortar | 19.0 |
| | 17 | 14 | 2 | 9 | 14 | Powder | 11.2 |
| | 10 | 10 | 4 | 7 | 10 | Wax | 6.6 |
| | 22.5 | 19.0 | 1.8 | 13.5 | 15.5 | Average | 14.4 |
| $CaSO_4$. | 32 | 32 | 5 | 5 | 10 | Neat | 16.8 |
| | 14 | 14 | 8 | 5 | 17 | Mortar | 11.6 |
| | 20 | 15 | 10 | 7 | 10 | Powder | 12.4 |
| | 14 | 11 | 2 | 0 | 7 | Wax | 6.8 |
| | 20.0 | 18.0 | 6.3 | 4.2 | 11.0 | Average | 11.9 |
| $Na_2SO_4$. | 12 | 24 | 20 | 20 | 17 | Neat | 18.6 |
| | 18 | 28 | 18 | 18 | 18 | Mortar | 20.0 |
| | 5 | 17 | 5 | 5 | 11 | Powder | 8.6 |
| | 5 | 22 | 5 | 0 | 22 | Wax | 10.8 |
| | 10.0 | 22.8 | 12.0 | 10.8 | 17.0 | Average | 14.5 |
| | 14.8 | 18.0 | 7.8 | 9.4 | 15.1 | Gen. Average | ..... |

The water-proofing processes experimented on were the mixing of a patent powder with the cement in one case, and the heating of each cylinder and the application to it of melted cerasin wax in the other.

Mr. Goodrich. Each jar thus contained four cylinders, one mixed neat, one with plain mortar, one with the powder compound, and one with the wax treatment. The specimens were so small, and so much uncertainty always exists about weighing wet specimens, that some inaccuracies doubtless crept in. Furthermore, the drawing of deductions from averages is often of doubtful value, but in such a case it seems to be the only method available for making comparisons. The percentage of increase (and, in one case, decrease in weight) was found as shown in Table 4, which also gives certain average values which may be summarized as follows:

The neat specimen suffered most; the plain mortar specimen next; the powder water-proofed specimen third; and the wax water-proofed specimen least, in the ratios of 17.6, 15.0, 12.2 and 7.9, respectively. Of the chemicals, sodium sulphate produced the worst result, with magnesium sulphate practically the same; while calcium sulphate, sodium chloride, and plain water produced practically identical results, but of less intensity. The increase in weight was due first, of course, to absorption, while chemical action appeared to follow in each case except that of plain water, as shown by either a precipitate or a scum which formed in or on the liquid, or by a gelatinous coating which formed on the outside of the cylinders. These deposits are now being examined chemically, as well as the surfaces of the cylinders, but it is not yet possible to give the results of the analyses.

Mr. Belknap. W. E. BELKNAP, M. AM. SOC. C. E. (by letter).—With a view to making accessible certain information which may have future value in its bearing on the durability of mortars exposed to the action of sea water, the writer submits Table 5, which is a record of the chemical and physical characteristics of the cement used in the construction of a concrete bulkhead wall in the Wallabout Basin, Brooklyn, N. Y., in 1896-97, together with a chart, Fig. 1, indicating the location in the wall of each particular lot of cement shown in Table 5. Fig. 1 will enable an investigator examining the work at any time to note whether the variations in physical and chemical characteristics are related to the variations in durability which he may find. The writer understands that, at the present time, the work shows no indications of disintegration.

The Wallabout Basin is on the East River, adjoining and east of the United States Navy Yard. The work in question is somewhat similar to that in the wall, built about the same time, around the "Cob Dock" of the Navy Yard, which has disintegrated seriously in many places. The writer's opinion is that the difference in durability is due very largely to methods of construction.

In the Wallabout wall every effort was made to secure a dense, impervious mortar in the face of the wall, special rammers, similar to ballast tamping bars, being used for that purpose. The specifications were as follows:

Mr. Belknap.

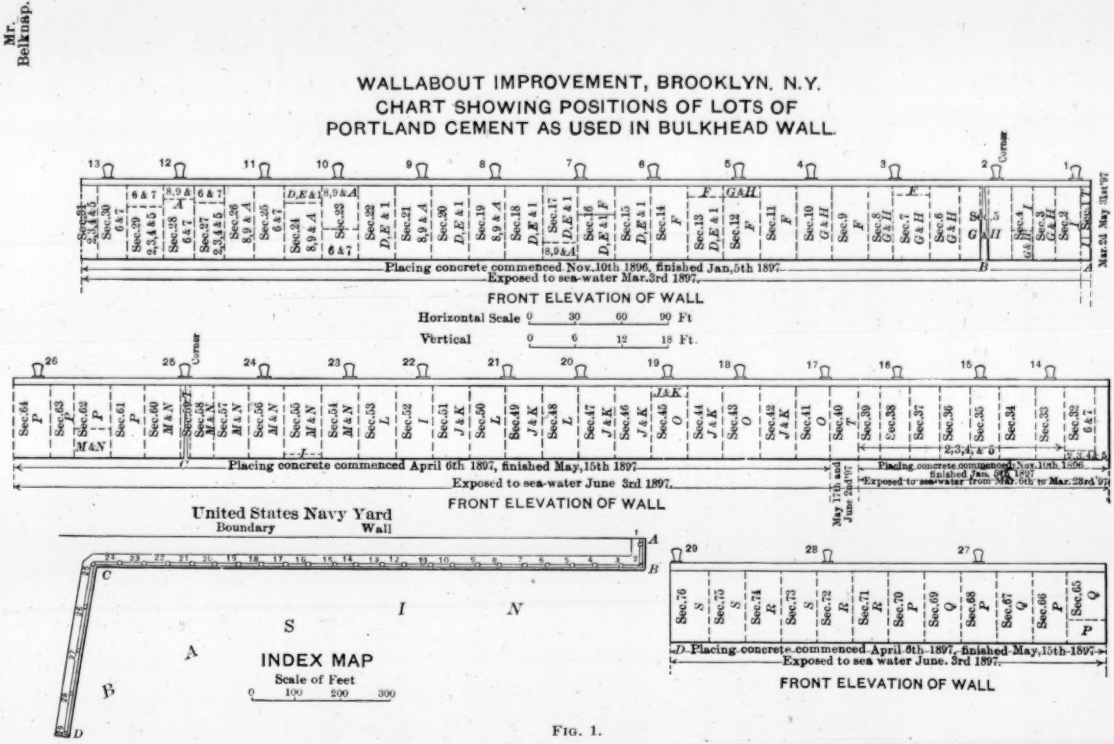


FIG. 1.

TABLE 5.—RECORD OF CEMENT TESTS, CONCRETE BULKHEAD WALL, WALLABOUT BASIN, BROOKLYN, N. Y.

| Lot designation. | Fineness. Percentage by weight of residue caught on: Number 50 sieve. | Number 100 sieve. | Number 200 sieve. | Composition. Parts in 100. Lime. | Silica. | Alumina. | Iron oxides. | Magnesia. | Sulphuric acid. | Hydraulic index. | Hydraulic index with magnesia. | Specific gravity. | Percentage of water to weight of cement. | Percentage of water to weight of sand and cement. | Initial set. Time to bear wire $\frac{1}{12}$ in. diam., weighing $\frac{1}{4}$ lb. H. | Initial set. Time to bear wire $\frac{1}{12}$ in. diam., weighing $\frac{1}{4}$ lb. M. | "Hard" set, Time to bear wire $\frac{1}{12}$ in. diam., weighing 1 lb. H. | "Hard" set, Time to bear wire $\frac{1}{12}$ in. diam., weighing 1 lb. M. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.0 | 12.2 | 30.0 | 60.52 | 21.74 | 7.20 | 3.45 | 3.18 | 1.45 | 47.97 | ..... | 3.08 | 18 | ..... | ..... | ..... | ..... | ..... |
| 2 | 0.9 | 12.0 | 32.0 | 58.68 | 23.10 | 7.80 | 3.43 | 3.72 | 1.048 | 52.8 | 49.6 | 3.08 | 15 | 9 | ..... | ..... | ..... | ..... |
| 3 | 0.71 | 10.19 | 30.325 | 55.30 | 23.93 | 8.48 | 2.74 | 2.82 | 0.99 | 55.0 | ..... | 3.174 | ..... | ..... | ..... | ..... | ..... | ..... |
| 4 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 5 | 1.0 | 12.1 | 34.0 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 6 | 1.0 | 12.5 | 32.0 | 59.50 | 23.14 | 7.97 | 3.05 | 3.84 | 1.065 | 52.28 | 49.12 | 3.00 | 15 | 8.5 | 3 | 10 | 6 | 45 |
| 7 | 0.44 | 9.7 | 20.5 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3.00 | 16 | ..... | 5 | 0 | 8 | 90 |
| 8 | 0.9 | 10.2 | 30.4 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3.08 | ..... | ..... | ..... | ..... | ..... | ..... |
| 9 | 0.9 | 12.0 | 32.0 | 59.72 | 23.88 | 7.62 | 3.06 | 3.76 | 0.80 | 52.75 | 49.62 | 3.08 | 16 | ..... | 2 | 10 | 5 | 90 |
| A | 0.5 | 9.8 | 29.925 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| D | 0.7 | 8.7 | 26.7 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| E | 0.75 | 11.65 | 27.65 | ..... | ..... | ..... | ..... | ..... | 0.956 | ..... | ..... | 3.07 | 16 | 8.5 | 2 | 0 | 5 | 45 |
| F | 0.5 | 7.7 | 25.0 | 59.96 | 23.12 | 7.90 | 2.92 | 3.90 | 0.828 | ..... | ..... | 3.09 | 16 | 8.5 | 1 | 0 | 3 | 0 |
| G | 0.5 | 4.7 | 22.2 | ..... | ..... | ..... | ..... | ..... | 0.914 | 50.8 | ..... | 3.05 | 16 | 8.5 | 3 | 10 | 6 | 0 |
| H | ..... | ..... | 23.0 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3.08 | 16 | 8.5 | 3 | 30 | 6 | 20 |
| I | 0.4 | 4.9 | 23.0 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3.09 | 16 | 8.5 | 3 | 30 | 6 | 0 |
| J | 0.3 | 3.6 | 13.6 | 60.08 | 22.34 | 7.24 | 2.56 | 4.02 | 1.07 | 49.24 | 46.15 | 3.09 | 16 | 8.5 | 2 | 30 | 5 | 35 |
| K | 0.4 | 3.7 | 13.8 | ..... | ..... | ..... | ..... | ..... | 1.027 | ..... | ..... | 3.06 | 16 | 8.5 | 2 | 45 | 5 | 45 |
| L | 0.2 | 4.8 | 23.0 | ..... | ..... | ..... | ..... | ..... | 1.037 | ..... | ..... | 3.06 | 16 | 8.5 | 0 | 45 | 2 | 50 |
| M | 0.5 | 4.3 | 23.0 | ..... | ..... | ..... | ..... | ..... | 1.140 | ..... | ..... | 3.06 | 18 | 9 | 0 | 50 | 2 | 50 |
| N | 0.4 | 4.0 | 24.0 | ..... | ..... | ..... | ..... | ..... | 1.130 | ..... | ..... | 3.07 | 18 | 9 | 1 | 20 | 4 | 25 |
| O | 0.7 | 4.2 | 28.0 | 59.64 | 22.50 | 7.83 | 2.96 | 3.56 | 1.120 | 50.9 | 48.0 | 3.06 | 18 | 9 | 1 | 5 | 4 | 30 |
| P | 0.7 | 4.6 | 27.0 | ..... | ..... | ..... | ..... | ..... | 1.130 | ..... | ..... | 3.06 | 18 | 9 | 1 | 15 | 5 | 15 |
| Q | 0.4 | 4.6 | 26.0 | ..... | ..... | ..... | ..... | ..... | 0.835 | ..... | ..... | 3.09 | 18 | 9 | 1 | 0 | 5 | 15 |
| R | 0.5 | 4.9 | 27.0 | 60.71 | 22.11 | 7.86 | 2.64 | 3.08 | 1.069 | 49.4 | 46.7 | 3.07 | 18 | 9 | 2 | 10 | 5 | 0 |
| S | 0.3 | 4.8 | 28.0 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3.06 | 18 | 9 | 1 | 30 | 5 | 30 |
| T | 0.3 | 4.8 | 28.0 | 61.94 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3.06 | 18 | 9 | 1 | 30 | 6 | 10 |
| B | 0.6 | 4.2 | 26.0 | 62.22 | 21.48 | 7.74 | 2.70 | 2.96 | 1.03 | 46.96 | 44.83 | 3.06 | 18 | 9 | 1 | 25 | 5 | 45 |

Mr. Belknap.

TABLE 5.—RECORD OF CEMENT TESTS—(*Continued*).

| Lot designation. | Tensile Strength. | | | | | | | | | | Number of barrels. | Average gross weight per barrel. | Date delivered. | Tensile Strength, 1 Year. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Neat. | | | | | | Sand, 1 : 3. | | | | | | | Neat. | | | | | | Sand, 1 : 3. | | | | | |
| | 1 day. | | 7 days. | | 28 days. | | 7 days. | | 28 days. | | | | | Air. | | Fresh water. | | Salt water. | | Air. | | Fresh water. | | Salt water. | |
| | Max. | Av. | Max. | Av. | Max. | Av. | Max. | Av. | Max. | Av. | | | | Max. | Av. | Max. | Av. | Max. | Av. | Max. | Av. | Max. | Av. | Max. | Av. |
| 1 | 292 | 289 | 830 | 806 | 908 | 888 | 214 | 205 | 280 | 275 | 100 | 380 | ..... | | | | | | | | | | | | |
| 2 | 168 | 159 | 598 | 589 | 735 | 718 | 120 | 117 | 190 | 172 | 250 | 384 | 3-11-'96 | | | | | | | | | | | | |
| 3 | .... | .... | ..... | ..... | ..... | ..... | .... | .... | .... | .... | 250 | 380.8 | 3-11-'96 | | | | | | | | | | | | |
| 4 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 250 | 383.5 | 4-11-'96 | | | | | | | | | | | | |
| 5 | 120 | 116 | 530 | 520 | 710 | 682 | 100 | 97 | 170 | 161 | 250 | 379.8 | 4-11-'96 | | | | | | | | | | | | |
| 6 | 92 | 88 | 610 | 587 | 685 | 669 | 130 | 127 | 244 | 232 | 250 | 384.8 | 10-11-'96 | | | | | | | | | | | | |
| 7 | .... | .... | ..... | ..... | ..... | ..... | .... | .... | .... | .... | 250 | 379.3 | 10-11-'96 | | | | | | | | | | | | |
| 8 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 250 | 380.9 | 22-11-'96 | | | | | | | | | | | | |
| 9 | 210 | 202 | 580 | 557 | 598 | 587 | 130 | 120 | 146 | 144 | 250 | 385.4 | 22-11-'96 | | | | | | | | | | | | |
| A | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 100 | 387.1 | 22-11-'96 | | | | | | | | | | | | |
| D | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 300 | 384.7 | 30-11-'96 | | | | | | | | | | | | |
| E | 170 | 161 | 590 | 563 | 744 | 708 | 138 | 130 | 220 | 204 | 300 | 383.8 | 30-11-'96 | | | | | | | | | | | | |
| F | 355 | 347 | 730 | 704 | 876 | 850 | 160 | 152 | 230 | 219 | 600 | 395.5 | 12-12-'96 | | | | | | | | | | | | |
| G | 472 | 460 | 740 | 723 | 920 | 898 | 152 | 148 | 215 | 207 | 300 | 393.5 | 19-12-'96 | | | | | | | | | | | | |
| H | 410 | 395 | 796 | 731 | 930 | 905 | 160 | 148 | 255 | 239 | 300 | 396.5 | 19-12-'96 | | | | | | | | | | | | |
| J | 338 | 277 | 820 | 773 | 890 | 880 | 172 | 161 | 290 | 280 | 250 | 399.3 | 26-12-'96 | | | | | | | | | | | | |
| J | 345 | 341 | 683 | 637 | 786 | 763 | 190 | 184 | 278 | 266 | 300 | ..... | 3-3-'97 | 1 050 | 1 012 | 940 | 888 | 1 110 | 1 068 | 260 | 247 | 440 | 418 | 422 | 403 |
| K | 370 | 352 | 628 | 587 | 770 | 736 | 200 | 162 | 244 | 239 | 300 | ..... | 3-3-'97 | | | | | | | | | | | | |
| L | 440 | 430 | 640 | 596 | 710 | 686 | 144 | 136 | 235 | 226 | 300 | 397.7 | 8-3-'97 | | | | | | | | | | | | |
| M | 342 | 327 | 640 | 602 | 750 | 712 | 186 | 180 | 255 | 235 | 300 | 397.7 | 8-3-'97 | | | | | | | | | | | | |
| N | 356 | 344 | 760 | 683 | 755 | 725 | 204 | 190 | 260 | 248 | 300 | 398.5 | 9-3-'97 | 1 006 | 945 | 980 | 922 | 1 060 | 990 | 260 | 236 | 408 | 392 | 420 | 394 |
| O | 354 | 345 | 652 | 623 | 755 | 708 | 150 | 146 | 262 | 249 | 300 | 398.5 | 9-3-'97 | | | | | | | | | | | | |
| P | 245 | 240 | 610 | 589 | 810 | 778 | 162 | 156 | 295 | 282 | 600 | 405.7 | 12-4-'97 | | | | | | | | | | | | |
| Q | 350 | 332 | 866 | 844 | 920 | 886 | 245 | 235 | 336 | 294 | 300 | 406.7 | 23-4-'97 | | | | | | | | | | | | |
| R | 366 | 349 | 830 | 799 | 750 | 659 | 256 | 248 | 382 | 351 | 300 | 405.7 | 21-4-'97 | | | | | | | | | | | | |
| S | 365 | 352 | 1 047 | 874 | 1 030 | 984 | 378 | 318 | 338 | 325 | 250 | 400.5 | 28-4-'97 | 896 | 870 | 1 020 | 988 | 1 060 | 1 018 | 270 | 244 | 404 | 395 | 416 | 393 |
| T | 406 | 391 | 1 000 | 933 | 1 052 | 1 017 | 374 | 349 | 342 | 333 | 250 | 399.0 | 30-4-'97 | | | | | | | | | | | | |
| B | .... | .... | ..... | ..... | ..... | ..... | .... | .... | .... | .... | .... | ..... | ..... | 930 | 896 | 944 | 907 | 1 020 | 985 | 140 | 119 | 360 | 341 | 402 | 382 |

Mr. Belknap.

"It will be built in forms or moulds to be furnished by the Contractor, set up *in situ* and strictly in accordance with the following rules:

"(*a*) The forms or moulds will be divided by vertical partitions set at right angles to the face of the wall, and the wall will be built by first filling every other section, and then the intermediate sections.

"The partitions will not be more than 24 feet nor less than 16 feet apart, and will come over short bents of piles.

"(*b*) Each section will be filled in layers not more than 8 inches thick, well rammed with cast-iron rammers of approved pattern, and each layer will be deposited throughout the section before the 'initial set' of the next layer underneath. When the work of filling a section is begun it must proceed without intermission to completion, working night and day if necessary; or if the Engineer permits or directs, the work will be stopped, the surface protected, during cessation of work, from foreign matter, and covered when work is resumed and just previous to the deposition of the next layer, with a thin layer of mortar, at least ¼ inch thick over entire surface, of cement and sand mixed one to one. In all cases a layer from one end to the other of a section must be completed without cessation of work.

"(*c*) The facing and backing will go on simultaneously, the layers being commenced at face of wall and worked toward the back, and with no defined lines of demarcation between the facing and the backing.

"(*d*) The planking of form on face of wall will be of tongued and grooved lumber dressed on inside face, and the entire inside face of mould or form must be true, smooth and free from all distortions.

"(*e*) The facing shall be carefully carried up and well worked against planking with a trowel or shovel before ramming, and it shall show a clear cement surface and no pits or irregularities. No plastering or washing with cement after the forms are removed will be allowed.

"(*f*) The concrete shall be mixed with no more water than it will take without quaking or showing a water surface under ramming.

"(*g*) From 5 to 10 barrels of cement will be kept well mixed dry in a suitable bin or box, and the cement for each batch of concrete will be drawn from this mixture.

"(*h*) The sand and cement will be thoroughly mixed dry before water is added, and the stone shall be thoroughly wet before mixed with the mortar.

"(*i*) There shall be but one quality or brand of cement in any one section.

"(*k*) The entire surface of the work shall be kept wet until the concrete is well set, to the satisfaction of the Engineer.

"(*l*) No mortar or concrete shall be made when the temperature is lower than 36° in the shade or when rain is falling on it, or when directed by the Engineer.

"(*m*) No mortar or concrete shall be used in the work after it has, in the opinion of the Engineer, attained its initial set.

"(*n*) No concrete will be laid in water or be exposed to water until set to the satisfaction of the Engineer, and the forms or moulds will be kept entirely free from water while concrete is being laid therein.

"The facing of the concrete wall and the top of the mooring post offsets will in all places be at least 8 inches thick, and will be composed of one part cement, two parts sand and from two to three parts of screenings or fine gravel. Mr. Belknap.

"The backing of the concrete wall will be composed of one part cement, two parts sand and four parts broken stone or gravel.

"The amount of stone in the concrete will be reduced if there is not, in the opinion of the Engineer, sufficient excess of mortar over the amount required to fill the voids in the stone.

"The cement to be used in this work will be furnished by the City, and will be delivered to the Contractor on the ground near the work at such times as the Engineer directs."

The chemical analyses and physical tests shown in Table 5 were made by the firm of Booth, Garrett and Blair, of Philadelphia, and it is the writer's recollection that the tensile strength is the average of four briquettes in each case.

GEORGE GRAY ANDERSON, M. AM. SOC. C. E. (by letter).—The writer had not intended this paper to be an exhaustive treatise on the whole subject, but rather, as was pointed out at the conclusion, a means of directing attention to specific failures which have occurred under conditions undoubtedly prevalent in the arid region, and of obtaining information as to methods of prevention and of cure, if such methods are known. Mr. Anderson.

It was by no means suggested that the failures had been general. The known failures have occurred, however, under conditions which, in the writer's observation, are frequently encountered, as Mr. Means has more fully pointed out, in certain cretaceous formations in the Rocky Mountain States, such as Pierre shale and the formations associated with it. It is desirable to know the nature of the deleterious compounds in these formations, the probable character and extent of the injuries they may effect, and the best methods of preventing and overcoming them.

It is reassuring to learn, from Mr. Means, that no disintegration has occurred on the Truckee-Carson Project, in Nevada, as it is well known that in that district there exist, as he states, "areas of land which contain large quantities of sodium sulphate and sodium chloride mixed." This statement may warrant the conclusion that these ingredients are not of themselves deleterious to concrete, and that for concrete work in alkaline areas, in which the ingredients are largely sodium sulphate and sodium chloride, special treatment of the concrete is not required. The further conclusion may be warranted that the construction of the concrete in the Truckee-Carson Project was such as to resist successfully the deleterious action of the alkali, and it would be greatly to the advantage of this discussion if the methods and character of that construction had been given somewhat in detail.

Mr. Anderson.

It is to be assumed that the work was of first-class quality, but so also was the work on the projects of the Reclamation Service in Montana and Wyoming, where failures occurred. In the Montana case, at least, the conclusion is inevitable that the disintegration was due to the presence of large quantities of magnesium sulphate.

From a comparison of these two cases alone, it may be concluded that alkalis composed principally of sodium sulphate and sodium chloride are harmless to concrete, while those containing large quantities of magnesium sulphate are most harmful.

On the other hand, Mr. Means has stated:

"The alkali which seems most harmful generally contains sodium and magnesium sulphates, chlorides, and some gypsum or calcium sulphate."

And further:

"Chlorides alone do not seem to be harmful, and sulphates of sodium and calcium are not harmful."

In giving the results of tests made during investigations of failure of cement tile in Utah, Mr. Hart finds "a remarkable weakening in the case of those stored in sulphate solutions," in which, "these results, although meager, seemed to indicate that sodium sulphate was the deteriorating factor, and that its effect was on the bond between the cement and the sand."

The tests made by Mr. Goodrich, with the modifying comment that "the drawing of deductions from averages is often of doubtful value," generally bear out those of Mr. Hart, in the general conclusion, at least, that "of the chemicals, sodium sulphate produced the worst result, with magnesium sulphate practically the same; while calcium sulphate, sodium chloride, and plain water produced practically identical results, but of less intensity."

Consideration of these tests alone would confirm the writer's opinion that the engineer must extend the field of his investigations materially before outlining plans, and that chemical analyses be made of the varying soils through which any particular project passes, with the purpose of determining whether structures in such soils require special treatment.

It would also confirm the opinion that there may be some special peculiarity of the local soil, as contrary to the view expressed by Mr. Robertson that "it is not the action of the alkali or the sea water, which varies from place to place, but the structures acted on," at least, as far as the action of the alkali is concerned.

It was not intended to convey the impression that concrete only was affected by the presence of alkali in the soils. It is undoubtedly true that brick and stone will be attacked, as Mr. Bates points out; and the writer has observed the disintegration of sandstone in the beds

Mr. Anderson.

of irrigation canals, also referred to by Mr. Bates. While the consideration was confined exclusively to concrete, it was hoped that the discussion, especially by those who had devoted much care to the chemical investigation of such failures, would treat the subject in its broader aspect.

That was also true of the effect of acids on concrete and other structural material, which has been considered at length, with much valuable comment, by Mr. Hering.

That porous concrete is subject to damage by alkali may be conceded as an axiom, even without requiring any analysis of the particular alkaline soil in any district. That would seem to be indicated clearly by the results in the case of tile pipes, as instanced in Professor Headden's investigations, and, further, by those quoted by Mr. Hart; in the latter case, "the tile were well made and well seasoned," and the salts were the chloride, carbonate, and sulphate of sodium. That, as above quoted, "seemed to indicate that sodium sulphate was the deteriorating factor, and that its effect was on the bond between the cement and the sand."

There would not appear to be any warrant for concluding that any particular brand of cement is more susceptible to damage than others; as Mr. Means has clearly pointed out, "all reputable brands have nearly the same composition."

It may be well enough, as a first step, to adopt the suggestion offered by Mr. Gaines, adapting to this particular class of damage Candlot's recommendation to eliminate the chemical side of the problem and rely solely on physical means of preventing the water from penetrating the mortar. It is clearly the duty of the engineer to construct as dense and non-porous a concrete as it is possible to obtain. That, however, is not the only consideration, as indicated in the paper and by some brief references in the discussion.

The careful investigation of the chemical constituents of the components of the concrete is absolutely essential, even the water, as referred to by Mr. Morse, though it has been seriously submitted that the quantity of water used in mixing the concrete is so small that its effect, even if strongly alkaline, would not be appreciable, a conclusion with which the writer cannot agree.

Beyond that, with effective drainage and the provision of a dense mass, the physical provisions would apparently be exhausted, unless some action, of a character unknown at present, is to be taken to counteract the rapid evaporation occurring in the warm, dry air of the arid region, which undoubtedly increases the opportunity for crystallization and, thereby, for disintegration.

Even after all has been done that can be done by improving the purely physical conditions, it cannot be otherwise than recognized that

Mr. Anderson.

the results, which are regarded with apprehension, even if, in relation to the great amount of work unaffected, they are comparatively small or even insignificant, are most largely due to chemical reactions, and this the present discussion has made illuminatingly clear—if it has done nothing else.

To the writer, as to Mr. Means, it would seem possible to produce a cement (varying sufficiently from the standard brands in items of composition) which will resist the decomposition and disintegration by alkaline salts, the chemical action of which would appear to be reasonably well determined; and, to the chemist, that problem must be left with confidence. The contributions to the discussion by Messrs. Bates and Gaines are not only valuable in themselves, but peculiarly so because of the information relating to the methods of investigation now being carried out, the results of which—not to be unduly deferred, it is hoped—will not only be of especial value to the Government, but to all who are engaged in the construction of works in districts affected by alkaline waters. These districts embrace a very wide territory, and are not confined to the arid region, though the results may be more immediately and more strikingly made apparent there.

# MEMOIRS OF DECEASED MEMBERS.

## HENRY FURLONG BALDWIN, M. Am. Soc. C. E.*

DIED JUNE 17TH, 1909.

Henry Furlong Baldwin died of apoplexy, at Seattle, Wash., on June 17th, 1909. By his death the Engineering Profession has sustained the loss of an eminent and forceful engineer, many members of this Profession, both young and old, have lost a strong and helpful friend, and the members of his family a dutiful brother, a kind and loving father, and an affectionate husband, for Mr. Baldwin was something more than a fine engineer, he was every inch a man.

He was born in 1862, the second of nine children, in Anne Arundel County, Maryland, of sturdy parents of Scotch-Irish and English descent. He was educated in the public schools, in the Anne Arundel Academy, and at the Massachusetts Institute of Technology, from which he was graduated in 1884, in the mechanical engineering course. He married Miss Pauline duPont, of Louisville, Ky., who, with three children, Paulina, Henry, and Meta, survives him.

After graduation, Mr. Baldwin chose to enter railroad work, and his first engagement was on the Cincinnati Division of the Louisville and Nashville Railroad until 1885. For a brief period afterward he was Rail Inspector at various steel mills. From 1885 to 1887, he was Supervisor of Track of the Knoxville Branch of the Louisville and Nashville Railroad, and for a short time in 1887 Roadmaster of the Pensacola and Atlantic Division of the Louisville and Nashville line. From 1887 to 1889, he was Roadmaster of the South and North Alabama Division of the Louisville and Nashville, at Birmingham.

From August, 1889, to March, 1890, Mr. Baldwin was Roadmaster on the Delaware Division of the New York, Lake Erie and Western Railway. From 1890 to 1894, he was Chief Engineer of the Chicago and Eastern Illinois Railroad. During this time a large portion of this road was rebuilt, involving a great deal of heavy work in the way of new masonry and bridge construction and reduction of grades, etc., also the construction of several new branch lines.

In May, 1894, Mr. Baldwin became Chief Engineer of the Chicago, Peoria and St. Louis Railway Company of Illinois, at Springfield, which position he held until he accepted that of Engineer of Maintenance of Way with the Erie Railroad, with office at Jersey City, N. J. He remained with the Erie until April, 1900, when he became Chief Engineer of the Chicago and Alton Railroad, with office at Chicago.

*Memoir prepared by W. D. Taylor, M. Am. Soc. C. E.

As Chief Engineer of the Chicago and Alton Railroad, Mr. Baldwin had charge of track maintenance, grade reduction, double-track construction, and the general rehabilitation of the property during the administration of S. M. Felton, M. Am. Soc. C. E. In 1904, he left the railway field and took a position as Vice-President of the duPont Powder Company, in charge of the Smokeless Powder Department, with office at Wilmington, Del. After three years of service with this company, he was appointed Chief Engineer of the Oregon and Washington Railroad, of the Harriman lines, with headquarters at Seattle, which position he held at the time of his death.

Mr. Baldwin was a man of forceful character and fine executive ability. He had a keen sense of humor, and frank, strong, manly qualities which easily won respect, confidence, and friendship. He loved to encourage and to show hospitality to the young men who worked for him. When his assistant engineers came in off the road to report to him, he would not permit them to go to hotels, but opened his home to them, and his delightful family made them welcome.

The writer was proud of the personal friendship of Mr. Baldwin. For the last four years, he has occupied the position on the Alton, which was held so long by Mr. Baldwin, and he has reason every day of his professional life to feel thankful for the character of the structures built and for the durable work done by this conscientious and thorough engineer.

Mr. Baldwin was a Member of the Western Society of Engineers, of the Chicago Club, of the Manhattan Club of New York City, and of the Rainier Club of Seattle, Wash.

Mr. Baldwin was elected an Associate Member of the American Society of Civil Engineers, on December 7th, 1892, and a Member, on February 6th, 1895.

## CLIFFORD BUXTON, M. Am. Soc. C. E.*

DIED JANUARY 12TH, 1910.

Clifford Buxton was born on June 15th, 1844, in Warren, Me. He was the only son of Doctor Benjamin F. Buxton, who was prominent in the medical profession of his State, having gained renown, in Mexico and the South, fighting the dreaded disease, yellow fever.

Clifford Buxton was recognized as a bright boy, and early became interested in the study of mathematics. Through an error on the part of his father in purchasing for him a Smith's Trigonometry and Surveying, instead of an algebra, he became so interested that he took up surveying, thus beginning his professional career. At the age of fifteen, he and his chum, the late Frederic W. Vaughan, M. Am. Soc. C. E., who, in later years, became an eminent bridge engineer, succeeded in securing an old surveyor's compass and a four-rod chain with which they made surveys of every lot in their native village.

In 1861, Mr. Buxton was a Chainman on a survey of public lands in Northern Maine. In September, 1862, he entered Rensselaer Polytechnic Institute, from which he was graduated with high standing in July, 1865.

Shortly after his graduation Mr. Buxton entered the service of the Troy and Boston Railroad Company (now part of the Boston and Maine), first as a Leveler, and afterward as Draftsman. In the spring of 1866 he was engaged as Draftsman for the Pittsburg, Fort Wayne and Chicago Railway Company, and, being desirous of getting experience in construction, he accepted a position as Leveler for the Cleveland and Mahoning Railroad (now part of the Pennsylvania Lines), to work on a proposed extension of the line from Youngstown, Ohio, to Pittsburg, Pa. At this time, however, only the surveys were made. In July, 1866, he was appointed Assistant Engineer, under William H. Searles, M. Am. Soc. C. E., on the Allegheny Valley Railroad, then being extended to Franklin, Pa., which service terminated with the completion of the division under his charge.

In October, 1867, Mr. Buxton was engaged as Leveler on the preliminary surveys for the Knox and Licking Railroad (now a part of the Maine Central), after which he was appointed as Principal Assistant Engineer in charge of the location and construction of thirty miles of the same road; this was completed in 1871.

In July, 1871, he was appointed United States Assistant Engineer in charge of the surveys of Horse Shoe Shoals, Delaware River, under Lieutenant-Colonel J. D. Kurtz. He resigned this position to accept that of Principal Assistant Engineer of the Cleveland, Mount Vernon

* Memoir prepared by R. P. Black, Assoc. M. Am. Soc. C. E.

and Delaware Railroad (now part of the Pennsylvania Lines, West), where he remained until the completion of the railroad. In July, 1874, he was appointed Assistant Chief Engineer of the Scioto Valley Railroad (now part of the Norfolk and Western), then under construction, remaining until the completion of the road.

In May, 1879, Mr. Buxton became Assistant Chief Engineer of the Columbus and Sunday Creek Valley Railroad (now a part of the Toledo and Ohio Central Railway). On February 1st, 1881, he was elected Chief Engineer of the Toledo and Ohio Central Railway, which position he held until his death on January 12th, 1910. He also served as Chief Engineer of the allied railroads, the Kanawha and Michigan Railway, until July, 1909, and after July, 1909, of the Zanesville and Western Railway.

Mr. Buxton was married to Miss Lucinda M. Andrews, of Warren, Me., on December 9th, 1868. He was a Thirty-second Degree Mason and a member of the Order of the Mystic Shrine.

Mr. Buxton was one of the pioneer engineers of railroad building in the East and Middle West. Many a monument to his career, in the way of masonry bridges, yet remains on several of the trunk lines to bespeak his ability. He was an engineer of exactness, a man of few words, of strong character, and a personality which marked him as an individual. It is said of Mr. Buxton that he could impart more information in a few pencil notes than another man could in lengthy letters.

He is survived by his wife and daughter, his only child, Mrs. Hubert B. Turner, of Boston, Mass.

Mr. Buxton was elected a Member of the American Society of Civil Engineers on May 6th, 1885.

## WILSON CROSBY, M. Am. Soc. C. E.*

DIED DECEMBER 18TH, 1904.

Wilson Crosby, son of William Chase Crosby and Harriet Chase, was born in Atkinson, Me., on October 18th, 1834. He was the eldest son in the eighth generation from Simon Crosby who settled in Billerica, Mass., in 1635, having come to the United States from Lancashire, England. The family traces back to 1204.

Wilson Crosby received his education through the public schools. In 1851, he entered Rensselaer Polytechnic Institute, at Troy, N. Y., and was graduated from the four-year course in Civil Engineering, after three years' work, in 1854. He practiced his profession with the New York and New England Railroad Company, in Connecticut; with the Maine Central Railroad, and with the European and North American Railroad, in Maine; with the New York, Utica, and Ogdensburg Railroad; with the Racine and Mississippi Railroad; with the Canada, Michigan, and Chicago Railroad; with the Spring Hill and Parsborough Railroad; and also on the Poughkeepsie Bridge approaches. For many years he was associated with Mr. Luther H. Eaton, as "Eaton and Crosby," at Bangor, Me.

At the outbreak of the Civil War, Mr. Crosby was put in charge, for the Government, of some construction at Fort Knox, Maine. He soon, however, helped raise a company of infantry, and went into active service as Second Lieutenant, Company I, 14th Maine Volunteers. He served until mustered out on September 25th, 1865, when he resumed the practice of his profession in New York City and elsewhere. He was connected for a time with work on Central Park and also on Riverside Drive. Later, as Division Engineer, he had charge of a part of the construction of Prospect Park, Brooklyn, including that portion known as "The Plaza."

In 1882-83, a company proposed to build an underground railroad and street under Broadway, in New York City, and Mr. Crosby was made Chief Engineer. Plans for "The Arcade" were prepared under his direction, but the capital not being forthcoming, the scheme was abandoned. In 1887, he was selected jointly by the New York and New England Railroad and the New York, New Haven and Hartford Railroad Companies to act as Chief Engineer for both companies in the abolishment of the grade crossings in Hartford, Conn., which he carried through to a successful conclusion. Such work was new then, and precedents for details were correspondingly scarce. The 80-ft. plate girders spanning Asylum Street were considered curiosities.

* Memoir prepared by W. W. Crosby, M. Am. Soc. C. E.

Mr. Crosby's father had died in 1880, and had left to his executorship several thousand acres of timber lands. About this time (1888), it became evident that he would have to devote practically his entire time to caring for this property, or the lands would have to be disposed of, probably at considerably less than their true value. The property was shared by his stepmother, his sister, and two brothers. With characteristic self-sacrifice, he thereupon made his decision, abandoned his beloved profession, in which he was just beginning to feel that he had won a substantial footing, and, in Bangor, Me., devoted his entire time to caring for the property which meant so much to others. With his usual thoroughness, he performed his new work and eventually made a success of it, though, for many years, the comparisons between his actual conditions and those which appeared to be promising in his profession at the time of his leaving it were sharp. Quietly and unobtrusively his deeds established for him such a record of uprightness, good judgment, honesty, and generosity, that many sought his help and advice in business affairs, and much property was entrusted to his guardianship. His business interests lay mostly in timber lands, and he early realized the dangers of forest destruction. The Maine Lumbermen and Land Owners Association he served faithfully, being one of its originators, and, for eight years, its Secretary and Treasurer. He was one of the first to demand the improved method of sawing rather than axing down trees. His plan met with much ridicule at first, but he clearly saw the advantages, patiently persisted, and finally had the satisfaction of seeing his ideas generally adopted.

For some time before his death, Mr. Crosby's health showed the strain he had undergone by his unselfish devotion to duty and unremitting attention to business affairs. His physicians advised him to take a complete rest, but his feeling of responsibility for the trust reposed in him by his father, and his belief that his utmost efforts were still necessary to fulfill that trust properly and to protect the property from the ravages of those who sought to despoil it through technicalities, made him unwilling to consider himself. In October, 1904, he was finally persuaded by his family to remove to the residence of his son in Baltimore, Md., but his death from uræmia followed within two months.

As an Engineer, Mr. Crosby possessed attainments of an exceptionally high order, much higher than the opportunities afforded by his limited practice of his profession allowed him to demonstrate. His native modesty and diffidence, together with the interruption of his professional work referred to, prevented the proper exemplification of his abilities to the world at large, though they were well known to his intimates. He combined, in a superlative degree, knowledge, thoroughness, honesty, and energy. While his professional acquaintances and work will bear witness to these statements, probably his greatest

contribution to the Profession and the common weal came from his kindly and improving influence on those fortunate enough to have been his subordinates or co-workers.

In November, 1871, Mr. Crosby married Miss Hannah Adelaide Seaver, daughter of William Whitney Seaver, of Brooklyn, N. Y. They had two children, Miss H. Gertrude Crosby and Walter Wilson Crosby, M. Am. Soc. C. E., who, with Mrs. Wilson Crosby, now live in Baltimore, Md.

Mr. Crosby was a Member of The Sons of the American Revolution, of the Loyal Legion, and a Past Commander of Hannibal Hamlin Post, G. A. R., of which he was one of the founders. Mr. Crosby was a man of unusually high character, and his qualities of heart and mind endeared him in the highest degree to those who were favored with his intimate acquaintance. For many years he was a leading spirit and substantial support of the Unitarian Church, of Bangor, Me.

His epitaph reads:

"An upright, honorable, unpretentious, Christian gentleman: he has left an inspiring example of usefulness, kindliness, and ability, and an unblemished record of modest and true worth."

Mr. Crosby was elected a Member of the American Society of Civil Engineers, on September 15th, 1869.

## JOHN HALL EMIGH, M. Am. Soc. C. E.*

DIED JANUARY 6TH, 1910.

John Hall Emigh was born in Malta, Saratoga County, New York, on November 19th, 1850. He was the son of William W. and Eliza (Hall) Emigh.

After finishing his elementary education, he attended the State Normal School at Albany, N. Y., from which he was graduated in 1871. From 1871 to 1876 he taught in district schools. In April, 1876, he became a student at the Rensselaer Polytechnic Institute, from which he was graduated in June, 1879, with the degree of C. E.

The record of Mr. Emigh's professional engagements is as follows:

1879—Rodman on the Chicago and Alton Railroad in Illinois.

1880-81—Engineer and Draftsman for the Saratoga Victory Manufacturing Company, Victory Mills, N. Y.

1882-83—Transitman and Draftsman on the survey of the Boston, Hoosac Tunnel and Western Railroad, Western Division.

1883-96—Instructor in the Departments of Mathematics and Surveying at the Rensselaer Polytechnic Institute.

1896-1903—City Engineer of North Adams, Mass.

1903-10—Engaged in private practice in hydraulic and municipal work in the vicinity of North Adams, Mass.

Mr. Emigh was actively engaged in his professional work to within twenty-four hours of his death. Always having had good health, he had great capacity for work, and thoroughly enjoyed the active life which he led.

Taking up the municipal work of North Adams, Mass., when it became a city, he solved with care and skill the many troublesome problems which arose.

Mr. Emigh's friends will always remember him as a Christian man, ever ready to help by words and deeds every good cause in civic, charitable, church, or social work. In his private life, as in his professional work, he was reliable, clean, and straightforward. Kindliness, loyalty, and faithfulness in the performance of every duty, characterized his teaching and his professional work.

The esteem felt for him by those who were associated with him is well expressed by one of the Commissioners of the Greylock Reservation, the engineering work of which was under Mr. Emigh's charge, as follows:

"To those who knew Mr. Emigh the news of his death came like a bolt from a clear sky. His was a most attractive personality. Thoughtful, conservative, of the best training, kindly in manner, he impressed

* Memoir prepared by E. R. Cary, M. Am. Soc. C. E.

all with whom he came in contact with his rugged honesty. In his chosen profession he was diligent, skillful, and his opinions were weighed with care and carefully stated. It was a pleasure to be associated with him in any undertaking. He had that broad common sense that could grapple with any problem presented. * * * He was the type of man that every community needs. Above all he was a Christian gentleman. We shall miss Mr. Emigh."

On March 3d, 1880, Mr. Emigh married Emma F. Allen, daughter of David Allen, of Malta, N. Y. His wife and one son, William C. Emigh, a graduate of the Rensselaer Polytechnic Institute of the class of 1909, survive him.

Mr. Emigh was elected a Member of the American Society of Civil Engineers, on April 3d, 1901.

## HENRY CYPRIAN HUMPHREY, M. Am. Soc. C. E.*

DIED DECEMBER 7TH, 1909.

Henry Cyprian Humphrey, son of Cyprian Nicholas and Louise Davies Humphrey, was born in Ogdensburg, N. Y., on November 14th, 1859. After his father's death, in 1860, the family moved to Hartford, Conn., to the home of his grandfather, Lemuel Humphrey, who was one of the oldest settlers and most influential citizens of that city.

After going through the public schools of Hartford, Mr. Humphrey entered the Rensselaer Polytechnic Institute, from which he was graduated, in 1887, with the degree of C. E. After receiving his degree, he was appointed Assistant Engineer on the Rome, Watertown, and Ogdensburg Railroad, and remained with that road until it was merged with the New York Central and Hudson River Railroad.

He was then made Assistant Engineer of the Department of Public Works of the State of New York, which position he held until overwork obliged him to take a vacation. This vacation was spent in traveling through the Northwest, Alaska, Arizona, Cuba, Mexico, and South America, where he made extensive collections of minerals and flora. The excavations made by him in the country of the Cliff Dwellers made his collection rank among the most complete amateur collections extant.

In 1903, Mr. Humphrey was appointed District Engineer of the Philippine Islands, Lucena, Tayabas Province, Tayabas, etc. He remained in the Islands in this capacity, taking no vacation, until the winter of 1908, when his failing health rendered a rest and change of climate necessary.

Returning to the United States, Mr. Humphrey spent a quiet year with relatives in Odessa, N. Y., endeavoring to recuperate so as to return to the position in the Philippines which was held open for him. He suddenly became much worse, however, and passed away on December 7th, 1909.

Mr. Humphrey was a Member of the Delta Phi Club of New York City, the South American Exploration Company, and was a Free Mason.

In his work in his chosen profession, Mr. Humphrey was second to none, holding the respect of all who knew him in a business capacity, and the love, admiration, and loyalty of all whom he honored with his friendship, for

> "His was the most tender, true, and noble soul
> That ever trod this world of ours as man."

Mr. Humphrey was elected an Associate Member of the American Society of Civil Engineers on September 4th, 1901, and a Member on October 3d, 1905.

* Memoir prepared by Miss Harriet Fairchild Blodgett.

## HENRY MAYNADIER STEELE, M. Am. Soc. C. E.*

DIED JULY 5TH, 1909.

Henry Maynadier Steele was born in Baltimore, Md., on September 26th, 1865, and died in Asheville, N. C., on July 5th, 1909. He was a son of Isaac Nevett and Rosa (Nelson) Steele, of Baltimore. In 1882, he was graduated from the Shenandoah Valley Academy, at Winchester, Va., as valedictorian of his class. Then for two years he attended the Massachusetts Institute of Technology as a special student.

Mr. Steele began his active business career in 1885, with the Baltimore and Ohio Railroad, with which company he occupied various minor positions in the Engineering and Maintenance of Way Departments, until 1887, when he entered the service of the New York, Lake Erie and Western Railroad Company (now the Erie Railroad Company) as Assistant Engineer on the work of double-tracking the Northern Railroad of New Jersey from Bergen Junction to Cresskill.

From 1887 to 1890, he was in charge of the following work on the New York, Lake Erie and Western Railroad: The reconstruction of the Hackensack River draw-bridge on the main line; the construction of the East Buffalo coal storage plant; the double-tracking of the Jefferson Branch of the Erie Railroad; the reconstruction of the Delaware River crossing at Hancock; the construction of second-track on the Northern Railroad of New Jersey, from Cresskill to Sparkill; preliminary and location surveys and estimates for a proposed railroad from Buffalo to Tonawanda, N. Y.; and surveys and estimates for a proposed railroad from Carbondale to Honesdale, Pa. For a portion of this time, he was also detailed as Roadmaster on the Delaware Division.

In December, 1890, Mr. Steele was advanced to the position of Principal Assistant Engineer of the same road, in which capacity he had charge of all detail work in the Chief Engineer's Department. During this time he also had charge of the reconstruction of the Chambers Street and Pavonia Avenue ferry racks, North River; and Pier No. 2, Shed No. 1, and a crib bulkhead and box sewer at Jersey City. The design and installation of interlocking and block signaling plants were also included in his general work; and, in August, 1891, he made a detailed inspection and report of all plants on the New York, Pennsylvania and Ohio Railroad and the Chicago and Erie Railroad, now parts of the Erie Railroad system. For some months, in the latter part of 1892, he was in charge of the Engineering Department of the New York, Lake Erie and Western Railroad, during the absence of the Chief Engineer.

* Memoir prepared by Francis Lee Stuart, M. Am. Soc. C. E.

Mr. Steele resigned in January, 1893, to establish the Southern Agency of the Hall Signal Company, with headquarters at Baltimore, Md., which position he held until April, 1894, when ill-health necessitated the stoppage of all active work for some time.

In the spring of 1894, he moved to Asheville, N. C., where for three years he was in consulting engineering practice. It was during this period that he was invited by the Society to prepare a paper, to be read at the Twenty-sixth Annual Convention at Niagara Falls, N. Y., on the subject of block signaling, but sickness prevented its final completion.

His health improving, in October, 1897, Mr. Steele was appointed Civil Engineer of the Central of Georgia Railway Company, reporting to the Vice-President. In this capacity he directed surveys and record maps of all terminals on that road, as well as the construction of the Andalusia extension of the Mobile and Girard Railroad. He designed the plant of the Atlantic Compress Company at Dotham, Ala.; constructed the Porterdale and Milledgeville Asylum spurs; and made a report on and an appraisal of the Kansas City Southern Railway and the Hawkinsville and Florida Southern Railway. In addition to his other duties at this time, he directed, as Chief Engineer, preliminary and location surveys, estimates, etc., of the Atlanta Belt Line.

In November, 1900, Mr. Steele was appointed Chief Engineer of the Central of Georgia Railway; and under his charge considerable work on the revision of grades and alignment was executed; many bridges were replaced with heavier structures; depots and warehouses, including the freight warehouse at Atlanta, Ga., and the passenger depot at Columbus, Ga., were rebuilt; the Henry Ellen Branch was extended into the Cahaba coal fields in Alabama; the Fort Oglethorpe and Army spur was built; and the Greenville and Newman Railway was partially completed. During this time he was also frequently called on as consulting engineer in connection with the design and valuation of cotton compress plants in Alabama and Mississippi.

In July, 1906, he was appointed Chief Civil Engineer of J. G. White and Company, Incorporated, of New York City, in charge of all civil engineering matters, with headquarters at New York City, which position he held at the time of his death. His duties during this period were of a general nature, involving consultations covering a wide field of engineering; investigations of various projects, etc.; and also, in an administrative capacity, the carrying out of the construction work of the Norfolk and Southern Railway, in North Carolina, comprising 90 miles of railroad, as well as 40 miles of the Virginian Railway lines in Virginia.

In the spring of 1908, just after recovering from an attack of typhoid fever, Mr. Steele conducted, unassisted by Counsel, a very arduous arbitration proceeding in the case of J. G. White and Company, Incorporated, *vs.* the Norfolk and Southern Railway Company.

In February, 1894, he married Miss Margaret Hollins McKim, of Baltimore, who, with three children, survives him.

Mr. Steele was an able, energetic, and efficient engineer; a man of sterling character; with the highest ideals of courtesy, honor, and integrity. He had the confidence and esteem of all who came in contact with him. With the exception of a few years of illness, his entire life was devoted to his profession, and his untimely death cut short a career that gave promise of still further honor and success.

Mr. Steele was a Member of the American Railway Engineering and Maintenance of Way Association; the Forestry Association; the National Geographic Society; and of the Engineers', New York Athletic, and Rockaway Hunting Clubs.

He was elected an Associate Member of the American Society of Civil Engineers on April 5th, 1893, and a Member on December 6th, 1899.

## JOHN JOSEPH HORAN, Assoc. M. Am. Soc. C. E.*

DIED NOVEMBER 9TH, 1909.

John Joseph Horan was born in New York City, in 1866. His father, John Horan, was a resident of Long Island City, where, for a number of terms, he held the office of City Treasurer, and where, for many years, his family was active in social and business life.

Mr. Horan was an only son, and received his education in the schools of New York City and in Cooper Union. In 1887 he became Superintendent of the Chemical Fertilizer Company, of Brooklyn, N. Y., and continued in this position until 1890, when he became Engineer in Charge of Construction of the works of the Clinton Metallic Paint Company, of Clinton, N. Y. He afterward became Superintendent in Charge of the operation of these works.

In 1896 he took charge of the construction of the petroleum refining plant of the Empreza Industrial de Patrolio, of Rio de Janeiro, Brazil. From 1898 to 1905, he was Superintendent of the extensive plants of Wilson Sons and Company, Limited, of London, England, at Rio de Janeiro and Bahia, Brazil, involving the operation of stone quarries, coaling stations, repairs to ships, tugs, and lighters, building of sea walls, maintenance of docks, wharves, etc.

In 1905, Mr. Horan returned to New York City, and after spending a few months as an Inspector in connection with the construction of the Pennsylvania Railroad tunnels under the North River, he obtained a position with the Board of Water Supply, on the construction force for the new Catskill Aqueduct. At the time of his death he was in charge of the borings for the proposed water distribution tunnel under New York City.

Mr. Horan's death occurred on November 9th, 1909, while he was on a short vacation to the Maine woods. While talking to friends at the door of the camp where he was staying, heart failure overtook him, and death came instantly. Apparently, he had been in the best of health and was in the prime of life.

Mr. Horan had that habit of mind which is characteristic of the successful engineer: painstaking attention to details, a love of mechanics, and a fair share of inventive genius. He had invented a number of mechanical contrivances which proved of value in the operation of paint and cement mills. He had perfected a rotary steam engine which operated with high efficiency. He was also responsible for the apparatus used by the Board of Water Supply to determine the condition of rock strata as to soundness in deep-rock borings along the line of the Catskill Aqueduct. He was thoroughly absorbed in his

* Memoir prepared by E. J. Fort, M. Am. Soc. C. E.

work, and, had not death so suddenly cut short his career, his continued success and an honored position in his profession were assured.

Mr. Horan was unmarried, and, with the exception of one sister, left no immediate family. He was of a disposition which made friends wherever he went, and those who knew him are unanimous in their testimony to his high character as a gentleman, his scrupulous integrity in all his transactions, and his faithfulness and generosity as a friend.

Mr. Horan was elected an Associate Member of the American Society of Civil Engineers on October 7th, 1908.

# TRANSACTIONS

OF THE

# American Society of Civil Engineers

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## INDEX

## VOLUME LXVII

JUNE, 1910

---

SUBJECT INDEX, PAGE 638

AUTHOR INDEX, PAGE 641

---

Titles of papers are in quotation marks when given with the author's name.

# VOLUME LXVII

## SUBJECT INDEX


**AGREEMENTS.**

*See* **CONTRACTS.**

**BRIDGES.**

"Notes on the Replacing of the Superstructure of the Harlem Ship Canal Bridge." Horace J. Howe. 1. Discussion: Lincoln Bush, Martin Gay, St. John Clarke, Theodore Belzner, and Frank W. Skinner, 23.

**BUILDINGS.**

"Agreements for Building Contracts." William B. Bamford. (With Discussion.) 438.

"Underpinning the Cambridge Building, New York City." T. Kennard Thomson. (With Discussion.) 553.

**CANALS.**

"Water Supply for the Lock Canal at Panama." Julio F. Sorzano. 61. Discussion: C. E. Grunsky, H. F. Hodges, Theodore Paschke, Allen Hazen, and C. M. Saville, 91.

**CEMENT.**

"The Effect of Alkali on Concrete." George Gray Anderson. (With Discussion.) 572.

**CONCRETE.**

"The Effect of Alkali on —." George Gray Anderson. 572. Discussion: R. A. Hart, Rudolph Hering, Richard L. Humphrey, George F. Morse, Richard H. Gaines, Thomas H. Means, F. E. Robertson, Philo H. Bates, E. P. Goodrich, and W. E. Belknap, 587.

**CONTRACTS.**

"Agreements for Building —." William B. Bamford. 438. Discussion: Norman R. McLure, William V. Polleys, Charles H. Higgins, W. G. Wilkins, William A. Boring, J. C. Wait, W. L. Bowman, Charles A. Ruggles, Oscar Lowinson, E. T. Thurston, Jr., John Mason Brown, J. A. L. Waddell, DeWitt V. Moore, and Leslie H. Allen, 478.

"Precarious Expedients in Engineering Practice." John Hawkesworth. (With Discussion.) 32.

**DAMS.**

Dam for improved water-works, Columbus, Ohio. 214.

**DRAW-BRIDGES.**

"Notes on the Replacing of the Superstructure of the Harlem Ship Canal Bridge." Horace J. Howe. (With Discussion.) 1.

**ENGINEERING.**

"Precarious Expedients in — Practice." John Hawkesworth. (With Discussion.) 32.

**ETHICS.**

"Precarious Expedients in Engineering Practice." John Hawkesworth. 32. Discussion: Eugene W. Stern, W. W. Crosby, J. S. Branne, Andrews Allen, Guy B. Waite, and J. H. Gandolfo, 46.

**EVAPORATION.**

"Water Supply for the Lock Canal at Panama." Julio F. Sorzano. (With Discussion.) 61.

**FILTRATION.**

"The Improved Water and Sewage Works of Columbus, Ohio." John H. Gregory. (With Discussion.) 206.

**FOUNDATIONS.**

"Underpinning the Cambridge Building, New York City." T. Kennard Thomson. 553. Discussion: Henry Gorton Opdycke, E. A. Yates, Ogden Merrill, Oscar Lowinson, and J. C. Meem, 565.

**LOCKS.**

"Water Supply for the Lock Canal at Panama." Julio F. Sorzano. (With Discussion.) 61.

**MEMOIRS OF DECEASED MEMBERS.**

Baldwin, Henry Furlong. 621.
Buxton, Clifford. 623.
Crosby, Wilson. 625.
Emigh, John Hall. 628.
Horan, John Joseph. 634.
Humphrey, Henry Cyprian. 630.
Steele, Henry Maynadier. 631.

**RAINFALL.**

"Water Supply for the Lock Canal at Panama." Julio F. Sorzano. (With Discussion.) 61.

**RESERVOIRS.**

"Water Supply for the Lock Canal at Panama." Julio F. Sorzano. (With Discussion.) 61.

**SAND-JACKS.**

— used in bridge erection. 21.

**SEPTIC TANKS.**

"The Improved Water and Sewage Works of Columbus, Ohio." John H. Gregory. (With Discussion.) 206.

**SEWAGE DISPOSAL.**

"The Improved Water and Sewage Works of Columbus, Ohio." John H. Gregory. 206. Discussion: Joseph W. Ellms, Julian Griggs, C-E. A. Winslow, R. D. Scott and R. F. McDowell, Samuel Tobias Wagner, J. Corbett, W. R. Copeland, W. A. Sperry, J. W. Sale, C. P. Hoover, C. B. Hoover, A. Elliott Kimberly, Samuel Rideal, Alexander Potter, Gilbert Fowler, William Gavin Taylor, Allen Hazen, William B. Fuller, Emil Kuichling, Langdon Pearse, Rudolph Hering, George A. Johnson, and George W. Fuller, 324.

**UNDERPINNING.**

*See* **FOUNDATIONS.**

**WATER.**

"The Improved — and Sewage Works of Columbus, Ohio." John H. Gregory. 206. Discussion: Joseph W. Ellms, Julian Griggs, C-E. A. Winslow, R. D. Scott and R. F. McDowell, Samuel Tobias Wagner, J. Corbett, W. R. Copeland, W. A. Sperry, J. W. Sale, C. P. Hoover, C. B. Hoover, A. Elliott Kimberly, Samuel Rideal, Alexander Potter, Gilbert Fowler, William Gavin Taylor, Allen Hazen, William B. Fuller, Emil Kuichling, Langdon Pearse, Rudolph Hering, George A. Johnson, and George W. Fuller, 324.

**WATER-WORKS.**

"The Improved Water and Sewage Works of Columbus, Ohio." John H. Gregory. (With Discussion.) 206.

## AUTHOR INDEX


**ALLEN, ANDREWS.**
Precarious engineering expedients. 52.

**ALLEN, LESLIE H.**
Agreements for building contracts. 520.

**ANDERSON, GEORGE GRAY.**
"The Effect of Alkali on Concrete." 572.

**BALDWIN, HENRY FURLONG.**
Memoir of. 621.

**BAMFORD, WILLIAM B.**
"Agreements for Building Contracts." 438.

**BATES, PHILO H.**
Effect of alkali on concrete. 608.

**BELKNAP, W. E.**
Effect of alkali on concrete. 612.

**BELZNER, THEODORE.**
Harlem Ship Canal Bridge. 27.

**BORING, WILLIAM A.**
Agreements for building contracts. 486.

**BOWMAN, W. L.**
Agreements for building contracts. 491.

**BRANNE, J. S.**
Precarious engineering expedients. 50.

**BROWN, JOHN MASON.**
Agreements for building contracts. 502.

**BUSH, LINCOLN.**
Harlem Ship Canal Bridge. 23.

**BUXTON, CLIFFORD.**
Memoir of. 623.

**CLARKE, ST. JOHN.**
Harlem Ship Canal Bridge. 26.

**COPELAND, W. R.**
Water and sewage works, Columbus, Ohio. 337.

**CORBETT, J.**
Water and sewage works, Columbus, Ohio. 335.

**CROSBY, W. W.**
Precarious engineering expedients. 48.

**CROSBY, WILSON.**
Memoir of. 625.

**ELLMS, JOSEPH W.**
Water and sewage works, Columbus, Ohio. 324

**EMIGH, JOHN HALL.**
Memoir of. 628.

**FOWLER, GILBERT.**
Water and sewage works, Columbus, Ohio. 394.

**FULLER, GEORGE W.**
Water and sewage works, Columbus, Ohio. 419.

**FULLER, WILLIAM B.**
Water and sewage works, Columbus, Ohio, 400.

**GAINES, RICHARD H.**
Effect of alkali on concrete. 602.

**GANDOLFO, J. H.**
Precarious engineering expedients. 57.

**GAY, MARTIN.**
Harlem Ship Canal Bridge. 24.

**GOODRICH, E. P.**
Effect of alkali on concrete. 611.

**GREGORY, JOHN H.**
"The Improved Water and Sewage Works of Columbus, Ohio." 206.

**GRIGGS, JULIAN.**
Water and sewage works, Columbus, Ohio. 325.

**GRUNSKY, C. E.**
Water supply for Panama Canal. 91.

**HAWKESWORTH, JOHN.**
"Precarious Expedients in Engineering Practice." 32.

**HAZEN, ALLEN.**
Water and sewage works, Columbus, Ohio. 399.
Water supply for Panama Canal. 108.

**HART, R. A.**
Effect of alkali on concrete. 587.

**HERING, RUDOLPH.**
Effect of alkali on concrete. 592.
Water and sewage works, Columbus, Ohio. 407.

**HIGGINS, CHARLES H.**
Agreements for building contracts. 481.

**HODGES, H. F.**
Water supply for Panama Canal. 96.

**HOOVER, C. B.**
Water and sewage works, Columbus, Ohio. 359.

**HOOVER, C. P.**
Water and sewage works, Columbus, Ohio. 354.

**HORAN, JOHN JOSEPH.**
Memoir of. 634.

**HOWE, HORACE J.**
"Notes on the Replacing of the Superstructure of the Harlem Ship Canal Bridge." 1.

**HUMPHREY, HENRY CYPRIAN.**
Memoir of. 630.

**HUMPHREY, RICHARD L.**
Effect of alkali on concrete. 598.

**JOHNSON, GEORGE A.**
Water and sewage works, Columbus, Ohio. 415.

**KIMBERLY, A. ELLIOTT.**
Water and sewage works, Columbus, Ohio. 379.

**KUICHLING, E.**
Water and sewage works, Columbus, Ohio. 402.

**LOWINSON, OSCAR.**
Agreements for building contracts. 496.
Underpinning buildings. 568.

**McDOWELL, R. F.**
Water and sewage works, Columbus, Ohio. 330.

**McLURE, NORMAN R.**
Agreements for building contracts. 478.

**MEANS, THOMAS H.**
Effect of alkali on concrete. 606.

**MEEM, J. C.**
Underpinning buildings. 569.

**MERRILL, OGDEN.**
Underpinning buildings. 567.

**MOORE, DeWITT V.**
Agreements for building contracts. 515.

**MORSE, GEORGE F.**
Effect of alkali on concrete. 601.

**OPDYCKE, HENRY GORTON.**
Underpinning buildings. 565.

**PASCHKE, THEODORE.**
Water supply for Panama Canal. 106.

**PEARSE, LANGDON.**
Water and sewage works, Columbus, Ohio. 406.

**POLLEYS, WILLIAM V.**
Agreements for building contracts. 479.

**POTTER, ALEXANDER.**
Water and sewage works, Columbus, Ohio. 390.

**RIDEAL, SAMUEL.**
Water and sewage works, Columbus, Ohio. 388.

**ROBERTSON, F. E.**
Effect of alkali on concrete. 608.

**RUGGLES, CHARLES A.**
Agreements for building contracts. 493.

**SALE, J. W.**
Water and sewage works, Columbus, Ohio. 345.

**SAVILLE, C. M.**
Water supply for Panama Canal. 112.

**SCOTT, R. D.**
Water and sewage works, Columbus, Ohio. 330.

**SKINNER, FRANK W.**
Harlem Ship Canal Bridge. 28.

**SORZANO, JULIO F.**
"Water Supply for the Lock Canal at Panama." 61.

**SPERRY, W. A.**
Water and sewage works, Columbus, Ohio. 342.

**STEELE, HENRY MAYNADIER.**
Memoir of. 631.

**STERN, EUGENE W.**
Precarious engineering expedients. 46.

**TAYLOR, WILLIAM GAVIN.**
Water and sewage works, Columbus, Ohio, 397.

**THOMSON, T. KENNARD.**
"Underpinning the Cambridge Building, New York City." 553.

**THURSTON, E. T., JR.**
Agreements for building contracts. 497.

**WADDELL, J. A. L.**
Agreements for building contracts. 510.

**WAGNER, SAMUEL TOBIAS.**
Water and sewage works, Columbus, Ohio. 334.

**WAIT, J. C.**
Agreements for building contracts. 488.

**WAITE, GUY B.**
Precarious engineering expedients. 55.

**WILKINS, W. G.**
Agreements for building contracts. 483.

**WINSLOW, C-E. A.**
Water and sewage works, Columbus, Ohio. 328.

**YATES, E. A.**
Underpinning buildings. 566.